CHAPTER III - SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

1. GENERAL

During the calendar year 1987, JTWC issued warnings on 25 different significant tropical cyclones in the western North Pacific -- six super typhoons, 12 typhoons, six tropical storms and one tropical depression. This includes one typhoon, Peke (02C), which initially developed in the central North Pacific (Table 3-1). The total number of western North Pacific tropical cyclones is lower than the climatological mean of 30.7, and two tropical cyclones below the 1986 total (Table 3-2). A record-setting eight significant tropical cyclones (all were of tropical storm intensity) developed in the North Indian Ocean. This is twice the climatological mean of four. Therefore, during 1987, JTWC issued warnings on a total of 33 northern hemisphere tropical cyclones.

During 1987 in the western North Pacific there were 139 "warning days". (A warning day is defined as a day during which JTWC was issuing warnings on at least one tropical cyclone. A "two-cyclone day" refers to a day when there were warnings issued on two different tropical cyclones simultaneously, a "three-cyclone day" -- three tropical cyclones at one time, and so on...). Considering only the western North Pacific, there were 30 two-cyclone days, 10 three-cyclone days and no four or five-cyclone days (Table 3-3). When North Indian Ocean tropical cyclones are included, there were 156 warning days, 38 two-cyclone days, 11 three-cyclone days and no four- or five-cyclone days. Thus, JTWC was in warning status 42.7 percent of the year; it was in a multiple-cyclone situation (that is, warning on two or more tropical cyclones) for 38 days or about 10.4 percent of the year.

JTWC issued <u>668</u> warnings on the 25 western North Pacific tropical cyclones (two warnings from January 1st on Typhoon Norris (26W) of 1986 are included in the total) and 83 warnings on the eight North Indian Ocean tropical cyclones, for a grand total of <u>751</u> warnings. There were thirty-one initial Tropical Cyclone Formation Alerts (TCFAs) issued for western North Pacific and eleven for the North Indian Ocean. Twenty-four western North Pacific and seven North Indian Ocean tropical cyclones developed subsequent to the issuance of a TCFA. Three of the western North Pacific tropical cyclones regenerated during their lifetime and each was covered by a TCFA. Typhoon Peke (02C) was passed to JTWC while in warning status and thus no TCFA was required (Table 3-4). For the western North Pacific, the false alarm rate was 24 percent and the mean lead time (to issuance of the first warning) was 13.5 hours. For the North Indian Ocean, the false alarm rate was 18 percent, with a mean lead time of 10.1 hours. One system (Tropical Cyclone 03A) was warned on without the benefit of a preceding TCFA.

2. WESTERN NORTH PACIFIC TROPICAL CYCLONES

The distinguishing features of 1987 in the western North Pacific were the low number of total tropical cyclones (25), the large number of super typhoons (6) and the number of "midgets" (4).

JANUARY THROUGH JUNE

The activity began in early in January with Typhoon Orchid (01W). Orchid (01W) was an unusually small system which transited the wintertime western North Pacific before being sheared apart by the northeast monsoon east of the Philippine Islands. The island of Ulithi experienced 100 kt (51 m/sec) winds and extensive damage when Orchid (01W) passed directly overhead. Tropical Storm Percy (02W) was the only significant tropical cyclone in April. It struggled to get started, but tenaciously resisted dissipation until it passed over the island of Luzon. Tropical Storm Ruth (03W) was a short-lived system which developed southeast of Hong Kong and eventually dissipated over southern China. Typhoon Sperry (04W) was the second tropical cyclone to reach typhoon intensity and also the second "midget" typhoon (Orchid (01W) was the first) of 1987. It was also the first to enter

TABLE 3-1. WESTERN NORTH PACIFIC 1987 SIGNIFICANT TROPICAL CYCLONES

TROPICAL CYCLONE			PERIOD OF WARNING	CALENDAR DAYS OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP - MB
01W	TY	ORCHID	08 JAN - 14 JAN	7	23	95 (49)	956
02W	TS	PERCY	11 APR - 13 APR	3	9	40 (21)	1000
03W	TS	RUTH	18 JUN - 19 JUN	2	6	35 (18)	997
04W	TY	SPERRY	27 JUN - 01 JUL	5	18	75 (38)	981
05W	STY	THELMA	07 JUL - 16 JUL	10	34	130 (67)	911
06W	TY	VERNON	16 JUL - 21 JUL	6	21	65 (33)	983
07W	TY	WYNNE	22 JUL - 01 AUG	11	40	125 (63)	921
08W	TY	ALEX	23 JUL - 28 JUL	6	22	65 (33)	976
09W	STY	BETTY	09 AUG - 16 AUG	8	32	140 (72)	891
10W	TY	CARY	13 AUG - 22 AUG	10	39	85 (44)	968
11W	STY	DINAH	21 AUG - 31 AUG	11	42	130 (67)	910
12W	TS	ED	22 AUG - 23 AUG	2	6	30 (15)	1001
12W	TS	ED*	26 AUG - 28 AUG	3	6	35 (18)	998
13W	TY	FREDA	04 SEP - 17 SEP	14	50	125 (63)	916
14W	TY	GERALD	04 SEP - 10 SEP	7	24	105 (53)	937
15W	STY	HOLLY	05 SEP - 15 SEP	11	43	140 (72)	898
16W	TY	IAN	23 SEP - 01 OCT	9	33	110 (56)	933
17W	TD	17W	24 SEP - 26 SEP	3	7	30 (15)	1000
02C	TY	PEKE	28 SEP - 03 OCT	6	23	100 (51)	941
18W	TS	JUNE	29 SEP - 01 OCT	3	9	35 (18)	997
19W	TY	KELLY	10 OCT - 16 OCT	7	28	95 (49)	950
20W	STY	LYNN	16 OCT - 27 OCT	12	44	140 (72)	898
21W	TS	MAURY	11 NOV - 12 NOV	2	4	30 (15)	1000
21W	TS	MAURY*	13 NOV - 19 NOV	7	25	45 (23)	991
22W	STY	NINA	19 NOV - 29 NOV	11	40	145 (75)	891
23W	TS	OGDEN	24 NOV - 25 NOV	2	4	35 (18)	997
24W	TY	PHYLLIS	10 DEC - 14 DEC	5	14	35 (18)	997
24W	TY	PHYLLIS*	14 DEC - 19 DEC	5	20	100 (51)	941
1987 TOTALS:				139**	668***		

* REGENERATED
** OVERLAPPING DAYS INCLUDED ONLY ONCE IN SUM.
*** YEAR-END TOTAL INCLUDES TWO WARNINGS ON TY NORRIS (26W) ON 01 JAN 87.

the mid-latitude westerlies and recurve toward the northeast.

JULY

Super Typhoon Thelma (05W) was the first of four significant tropical cyclones to develop in July and the first super typhoon of 1987. Forecasting the timing and location of recurvature presented a problem for JTWC. Dynamic forecast aids did indicate recurvature, but much sooner than was ultimately observed. After damaging northern Luzon and causing the evacuation of aircraft from Okinawa, Japan, Thelma (05W) slammed into Korea causing $124 million in damages and the loss of several hundred lives. Typhoon Vernon (06W) followed closely on the heels of Super Typhoon Thelma (05W). It was weak and disorganized throughout most of its life. As a result, initial positioning problems arose in the Philippine Sea due to differences between real-time fix information from radar, satellite and aircraft. Typhoon Wynne (07W) was the third "midget" typhoon of the season. It tracked along a constant bearing of 294 degrees for four days and maintained a visible eye for six days. Meteorologists on Kwajalein Atoll provided radar fix information which was instrumental in relocating Wynne (07W) early on. Wynne (07W) caused extensive damage as it passed through the northern Mariana Islands[1]. Typhoon Alex (08W) was the final tropical cyclone in July. Together with Wynne (07W) it formed the first multiple tropical cyclone situation during 1987. Alex (08W) brushed the eastern coast of Taiwan before making landfall on the coast of mainland China. Although damage to Taiwan and mainland China was relatively light, the remnants of Alex (08W) enhanced a band of precipitation that stalled over Korea, and as a consequence, 12 inches (308 mm) of rain fell in 24-hours causing major flooding and loss of life.

AUGUST

Super Typhoon Betty (09W) was the second super typhoon of the season and had the lowest reported minimum sea-level pressure (891 mb) up to that time. It explosively deepened just prior to making landfall in the Philippine Islands, where 20 people were killed and 60,000 left homeless. Typhoon Cary (10W), together with Betty (09W) and Dinah (11W) formed the first three-storm situation for 1987. The last scheduled western North Pacific aircraft reconnaissance mission was flown on Cary (10W) on the 15th of August. Cary (10W) eventually made landfall on the coast of northern Vietnam and ultimately dissipated over Burma. Super Typhoon Dinah (11W) was the most destructive typhoon to strike Okinawa and the southern islands of Japan in the past 20 years. Throughout its life, JTWC consistently forecast recurvature and accelerations towards the northeast through the Sea of Japan, as a result, Dinah's (11W) forecast track errors were smaller than average. Tropical Storm Ed (12W) was a very difficult tropical cyclone to locate and forecast due to fluctuations in its intensity, speed and track direction and its poorly defined

TABLE 3-2. WESTERN NORTH PACIFIC TROPICAL CYCLONE DISTRIBUTION

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0 000	1 010	1 010	1 100	0 000	1 001	3 111	8 512	9 423	3 210	2 200	2 200	31 17 7 7
1960	1 001	0 000	1 001	1 100	1 010	3 210	3 210	9 810	5 041	4 400	1 100	1 100	30 19 8 3
1961	1 010	1 010	1 100	1 010	4 211	6 114	5 320	7 313	6 510	7 322	2 101	1 100	42 20 11 11
1962	0 000	1 010	0 000	1 100	3 201	0 000	8 512	8 701	7 313	5 311	4 301	2 020	39 24 6 9
1963	0 000	0 000	1 001	1 100	0 000	4 310	5 311	4 301	4 220	6 510	0 000	3 210	28 19 6 3
1964	0 000	0 000	0 000	0 000	3 201	2 200	8 611	8 350	8 521	7 331	6 420	2 101	44 26 13 5
1965	2 110	2 020	1 010	1 100	2 101	4 310	6 411	7 322	9 531	3 201	2 110	1 010	40 21 13 6
1966	0 000	0 000	0 000	1 100	2 200	1 100	4 310	9 531	10 532	4 112	5 122	2 101	38 20 10 8
1967	1 010	0 000	2 110	1 100	1 010	1 100	8 332	10 343	8 530	4 211	4 400	1 010	41 20 15 6
1968	0 000	1 001	0 000	1 100	0 000	4 202	3 120	8 341	4 400	6 510	4 400	0 000	31 20 7 4
1969	1 100	0 000	1 010	1 100	0 000	0 000	3 210	3 210	6 204	5 410	2 110	1 010	23 13 6 4
1970	0 000	1 100	0 000	0 000	0 000	2 110	3 021	7 421	4 220	6 321	4 130	0 000	27 12 12 3
1971	1 010	0 000	1 010	2 200	5 230	2 200	8 620	5 311	7 511	4 310	2 110	0 000	37 24 11 2
1972	1 100	0 000	1 001	0 000	0 000	4 220	5 410	5 320	6 411	5 410	2 200	3 210	32 22 8 2
1973	0 000	0 000	0 000	0 000	0 000	0 000	7 430	6 231	3 201	4 400	3 030	0 000	23 12 9 2
1974	1 010	0 000	1 010	1 010	1 100	4 121	5 230	7 232	5 320	4 400	4 220	2 020	35 15 17 3
1975	1 100	0 000	0 000	1 001	0 000	0 000	1 010	6 411	5 410	6 321	3 210	2 002	25 14 6 5
1976	1 100	1 010	0 000	2 110	2 200	2 200	4 220	4 130	5 410	0 000	2 110	2 020	25 14 11 0
1977	0 000	0 000	1 010	0 000	1 001	1 010	4 301	2 020	5 230	4 310	2 200	1 100	21 11 8 2
1978	1 010	0 000	0 000	1 100	0 000	3 030	4 310	8 341	4 310	7 412	4 121	0 000	32 15 13 4
1979	1 100	0 000	1 100	1 100	2 011	0 000	5 221	4 202	6 330	3 210	2 110	3 111	28 14 9 5
1980	0 000	0 000	1 001	1 010	4 220	1 010	5 311	3 201	7 511	4 220	1 100	1 010	28 15 9 4
1981	0 000	0 000	1 100	1 010	1 010	2 200	5 230	8 251	4 400	2 110	3 210	2 200	29 16 12 1
1982	0 000	0 000	3 210	0 000	1 100	3 120	4 220	5 500	6 321	4 301	1 100	1 100	28 19 7 2
1983	0 000	0 000	0 000	0 000	0 000	1 010	3 300	6 231	3 111	5 320	5 320	2 020	25 12 11 2
1984	0 000	0 000	0 000	0 000	0 000	2 020	5 410	7 232	4 130	8 521	3 300	1 100	30 16 11 3
1985	2 020	0 000	0 000	0 000	1 100	3 201	1 100	7 520	5 320	5 410	1 010	2 110	27 17 9 1
1986	0 000	1 100	0 000	1 100	2 110	2 110	2 200	5 410	2 200	5 320	4 220	3 210	27 19 8 0
1987	1 100	0 000	0 000	1 010	0 000	2 110	4 400	4 310	7 511	2 200	3 120	1 100	25 18 6 1
(1959-1987) AVG	0.6	0.3	0.6	0.8	1.2	2.1	4.6	6.2	5.7	4.6	2.8	1.4	30.9
CASES	16	9	18	22	36	60	132	179	164	132	81	42	891

Legend: **Total for the month** → 6

Typhoons → 3 1 2

Tropical Storms

Tropical Depressions

The criteria used in the above table are as follows:

1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month - no matter how long the system lasted.
3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that tropical cyclone was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for two days only, then it was attributed to the second month.

[1]Personal communication with Mr. Paul M. Hattori of the U.S. Geological Survey (Department of Interior) revealed the following event of interest. Prior to 251145Z July there was no increase in microseismic activity on the World Wide Standardized Seismograph Network (WWSSN) long- and short-period records from the Mount Santa Rosa station (13° 32' 18" N, 144° 54' 42" E), Guam. From 251145Z to 251800Z, the short-period microseisms increased noticeably and were irregular in comparison to microseisms caused by higher surf levels or squall-like weather. After 251800Z, the background returned to approximately pre-251145Z levels. Also, the long-period microseisms approximately doubled in amplitude from 251000Z to 251700Z. The maximum being in the east-west component. Hence, the possibility exists that this unique microseismic activity may be coincident with, or causally related to, Typhoon Wynne's (07W) transit of the Mariana Trench. Similar activity has been observed with other tropical cyclones, but with less clarity. With an absence of other organized weather systems in the area, the typhoon's compact size and distance from the WWSSN station on Guam resulted in an unusually clear recording of Wynne's approach to the northern Marianas.

cloud signature. Drifting buoy reports of 30 kt (15 m/sec) were key to the decision to issue the first warning on Ed (12W).

SEPTEMBER

Typhoon Freda (13W) was the first of seven tropical cyclones to develop during September and was the middle (geographically) of a three-storm situation (the other tropical cyclones being Gerald (14W) and Holly (15W)). This was the second three-storm situation of the year. Freda (13W) was unusual because it traversed less than 10 degrees of longitude, but 25 degrees of latitude. Freda's (13W) thirteen day life span and 50 warnings were records for 1987. Typhoon Gerald (14W) was unique in that it matured within the monsoon trough, but did not detach from it. The most distinctive feature was its unusually large eye. Super Typhoon Holly (15W) was the third tropical cyclone to develop from the active monsoon trough which also spawned Freda (13W) and Gerald (14W). Although very intense, it had a very uneventful life as it recurved far to the east of Japan. After a six day respite in tropical cyclone activity, Typhoon Ian (16W) developed about 330 nm (611 km) to the east-northeast of Guam. Andersen Air Force Base Weather was able to provide several radar fixes of Ian (16W) as it passed to the north of Guam. It eventually recurved and transitioned to a sub-tropical system north of 25 degrees North Latitude. Tropical Depression 17W developed north of the Marshall Islands at about the same time as Ian. Tropical Depression 17W did not reach tropical storm strength because it was suppressed by the combined effects of the outflow from Ian (16W) and a mid-level short-wave trough to the north. Typhoon Peke (02C) was the first hurricane to form in the central North Pacific and cross to the western North Pacific in the past twenty years. It meandered basically north-northwestward and eventually dissipated just west of the dateline. Tropical Storm June (18W) was the third tropical cyclone of the final three-storm situation during 1987. Throughout its life, June's (18W) upper-level outflow was restricted by the strong outflow from Ian.

TABLE 3-3. WESTERN NORTH PACIFIC SUMMARY

TYPHOONS
(1945-1958)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
AVG	0.4	0.1	0.3	0.4	0.7	1.1	2.0	2.9	3.2	2.4	2.0	0.9	16.3
CASES	5	1	4	5	10	15	28	41	45	34	28	12	228

(1959-1987)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
AVG	0.2	0.1	0.2	0.5	0.7	1.0	2.8	3.2	3.3	3.0	1.7	0.7	17.4
CASES	7	2	6	15	19	30	80	94	96	87	48	20	504

TROPICAL STORMS AND TYPHOONS
(1945-1958)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
AVG	0.4	0.1	0.4	0.5	0.8	1.6	3.0	3.9	4.1	3.3	2.8	1.1	22.0
CASES	6	1	6	7	11	22	42	54	58	46	39	16	308

(1959-1987)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
AVG	0.5	0.3	0.5	0.7	1.0	1.8	4.1	5.2	4.9	4.1	2.6	1.3	27.0
CASES	15	8	14	21	30	51	120	151	142	118	76	37	783

FORMATION ALERTS: 24 of 34 Initial Formation Alerts developed into significant tropical cyclones (not including three on systems that regenerated). Tropical Cyclone Formation Alerts were issued for all of the significant tropical cyclones that developed in 1987.

WARNINGS:

Number of calendar warning days:	139
Number of calendar warning days with two tropical cyclones:	30
Number of calendar warning days with three tropical cyclones:	10

OCTOBER

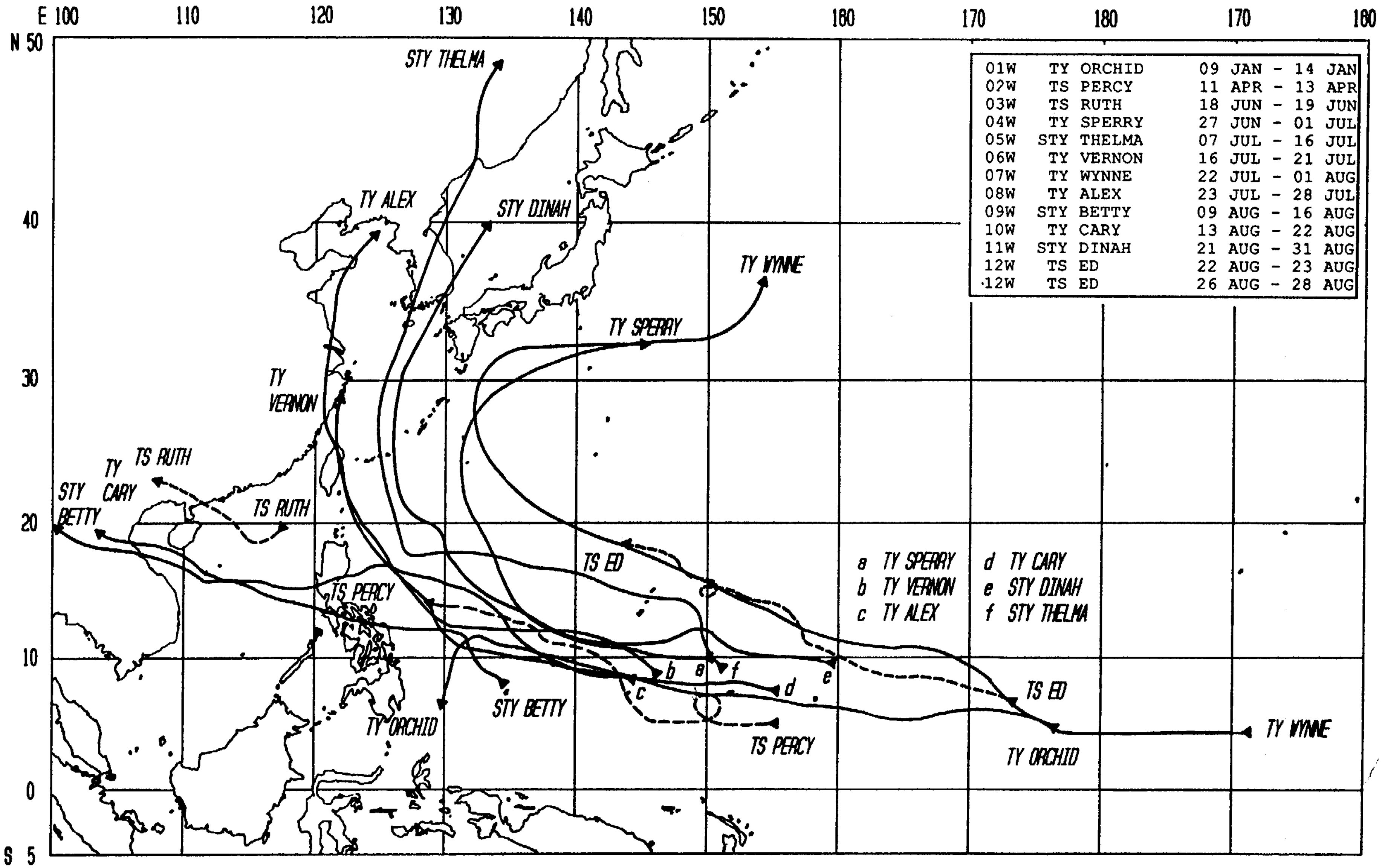
Typhoon Kelly (19W) was the first of only two significant tropical cyclones to occur during October. Kelly (19W) developed when the monsoon trough re-established itself in low-latitudes after it had been displaced to a position about 25 degrees North Latitude the previous week due to Ian (16W), June (18W) and Peke (02C). Super Typhoon Lynn (20W) was the fifth super typhoon of the year and the third to produce winds of at least 140 kt (72 m/sec). It attained a minimum sea-level pressure of 898 mb. At one point, Lynn (20W) appeared to be headed straight for Guam. Fortunately, a last minute jog toward the north spared the island from a direct hit. Saipan, which is north of Guam, received gusts to 65 kt (33 m/sec), however. Lynn (20W) eventually passed south Taiwan, enhanced convection and increased

TABLE 3-4. FORMATION ALERT SUMMARY WESTERN NORTH PACIFIC				
YEAR	NUMBER OF TCFAs	NUMBER OF SYSTEMS WARNED ON	TOTAL NUMBER OF SYSTEMS	FALSE ALARM RATE
1975	34	25	25	26%
1976	34	25	25	26%
1977	26	20	21	23%
1978	32	27	32	16%
1979	27	23	28	15%
1980	37	28	28	24%
1981	29	28	29	3%
1982	36	26	28	28%
1983	31	25	25	19%
1984	37	30	30	19%
1985	39	26	27	33%
1986	38	27	27	29%
1987	31	24	25	23%
(1975-1987) AVERAGE	33.1	25.7	26.9	21.8%
CASES	431	334	350	

wind speeds to the north that caused the deaths of 42 people. Over 68 inches (1744 mm) of rain fell on Taipei over a two day period due to Lynn (20W). Tropical Storm Maury (21W) was a relatively weak, but persistent, tropical cyclone which formed southeast of Guam and tracked basically westward across the Philippine Sea, through the Philippine Islands and into the South China Sea.

NOVEMBER THROUGH DECEMBER

Super Typhoon Nina (22W) was the sixth, and last, super typhoon. It also proved to be the most intense and destructive tropical cyclone of the year. Nina was interesting from a meteorological point of view because it unexpectedly intensified while still accelerating toward the west. It devastated Truk, killing five and injuring 38, before moving on to the Philippine Sea. Once there Nina (22W) explosively intensified, to 145 kt (75 m/sec), prior to making landfall. An estimated 658 people were killed on southern Luzon, making it the most destructive typhoon to hit the Philippine Islands in 20 years. Tropical Storm Ogden (23W) was another minimal tropical storm which developed in the South China Sea and moved westward before making landfall on the Vietnam coast, north of Cam Rahn Bay. Typhoon Phyllis (24W), the fourth "midget" of 1987, was the last tropical cyclone of the 1987 season. Phyllis (24W) formed southeast of Guam and initially followed what appeared to be a broad recurvature track, passing to the southwest of Guam. Unfortunately, it weakened, moved toward the west-southwest and then explosively intensified (to 100 kt (51 m/sec)) before striking the island of Samar in the central Philippine Islands and moving into the South China Sea.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03W TS RUTH 18 JUN - 19 JUN
04W TY SPERRY 27 JUN - 01 JUL
05W STY THELMA 07 JUL - 16 JUL
06W TY VERNON 16 JUL - 21 JUL
07W TY WYNNE 22 JUL - 01 AUG
08W TY ALEX 23 JUL - 28 JUL
09W STY BETTY 09 AUG - 16 AUG
10W TY CARY 13 AUG - 22 AUG
11W STY DINAH 21 AUG - 31 AUG
12W TS ED 22 AUG - 23 AUG
12W TS ED 26 AUG - 28 AUG
STY THELMA
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TY VERNON
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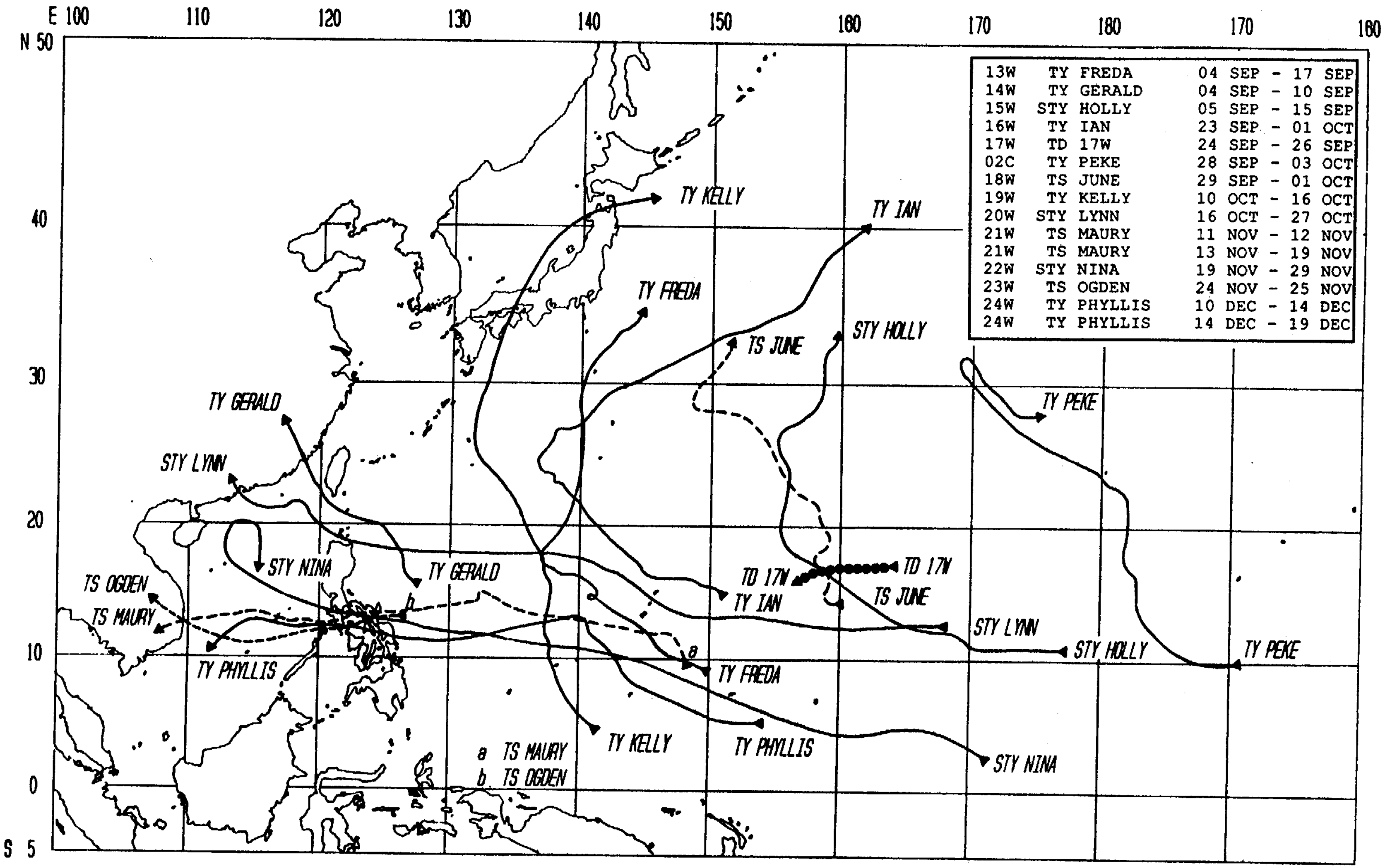

13W TY FREDA 04 SEP - 17 SEP
14W TY GERALD 04 SEP - 10 SEP
15W STY HOLLY 05 SEP - 15 SEP
16W TY IAN 23 SEP - 01 OCT
17W TD 17W 24 SEP - 26 SEP
02C TY PEKE 28 SEP - 03 OCT
18W TS JUNE 29 SEP - 01 OCT
19W TY KELLY 10 OCT - 16 OCT
20W STY LYNN 16 OCT - 27 OCT
21W TS MAURY 11 NOV - 12 NOV
21W TS MAURY 13 NOV - 19 NOV
22W STY NINA 19 NOV - 29 NOV
23W TS OGDEN 24 NOV - 25 NOV
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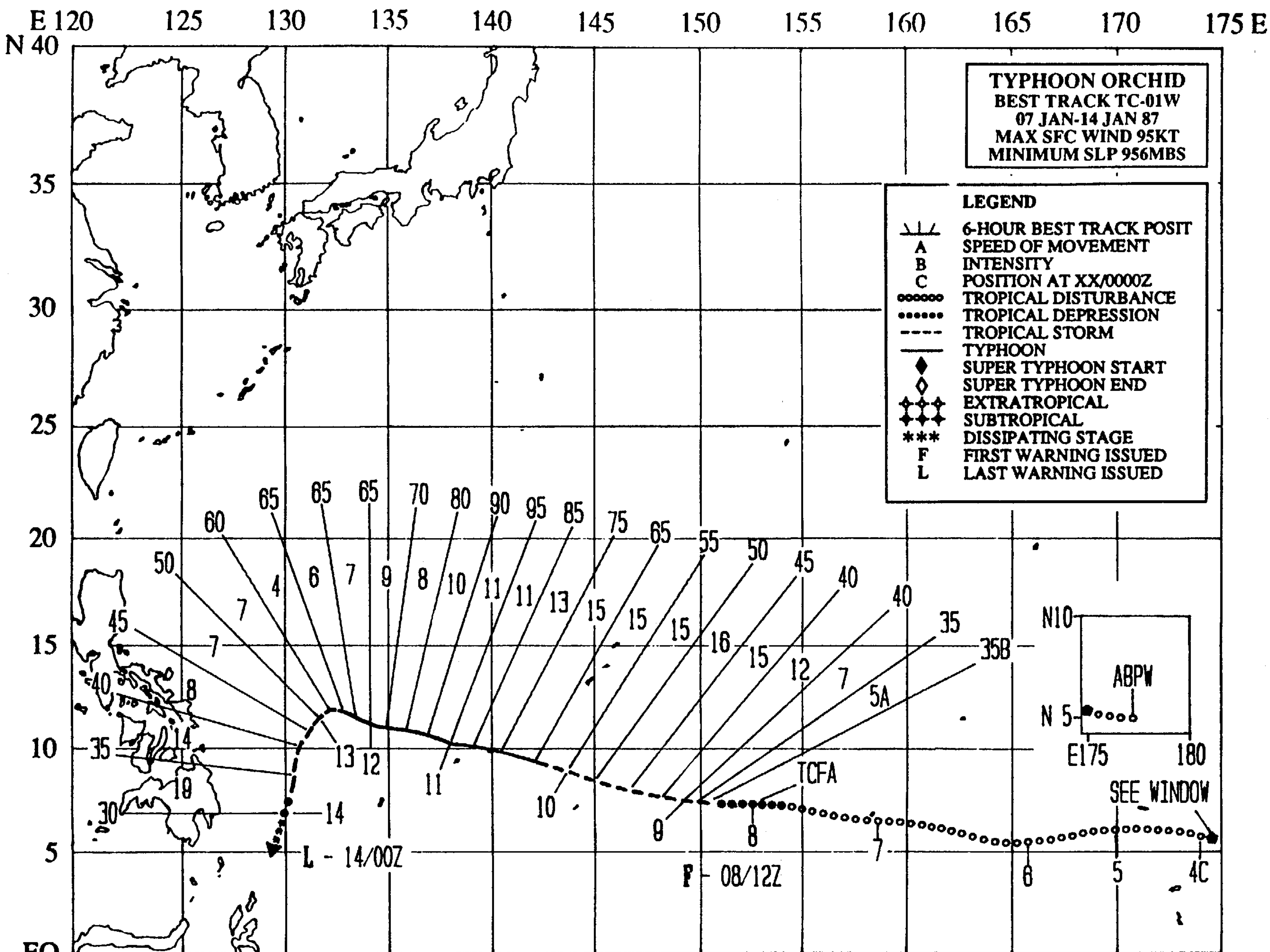
TYPHOON ORCHID
BEST TRACK TC-01W
07 JAN-14 JAN 87
MAX SFC WIND 95KT
MINIMUM SLP 956MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
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135
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145
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165
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L - 14/00Z
F - 08/12Z
TCFA
SEE WINDOW
N10
N 5
E175
180
ABPW
4C
35B
5A

TYPHOON ORCHID (01W)

Typhoon Orchid (01W), the first tropical cyclone of 1987, was an unusually small system. It transited across the wintertime western North Pacific before being sheared apart by the northeast monsoon east of the Philippines.

The disturbance that eventually developed into Typhoon Orchid was first detected at 0000Z on January 3rd as a small area of persistent convection in the near-equatorial trough near the dateline. It was first mentioned on the Significant Tropical Weather

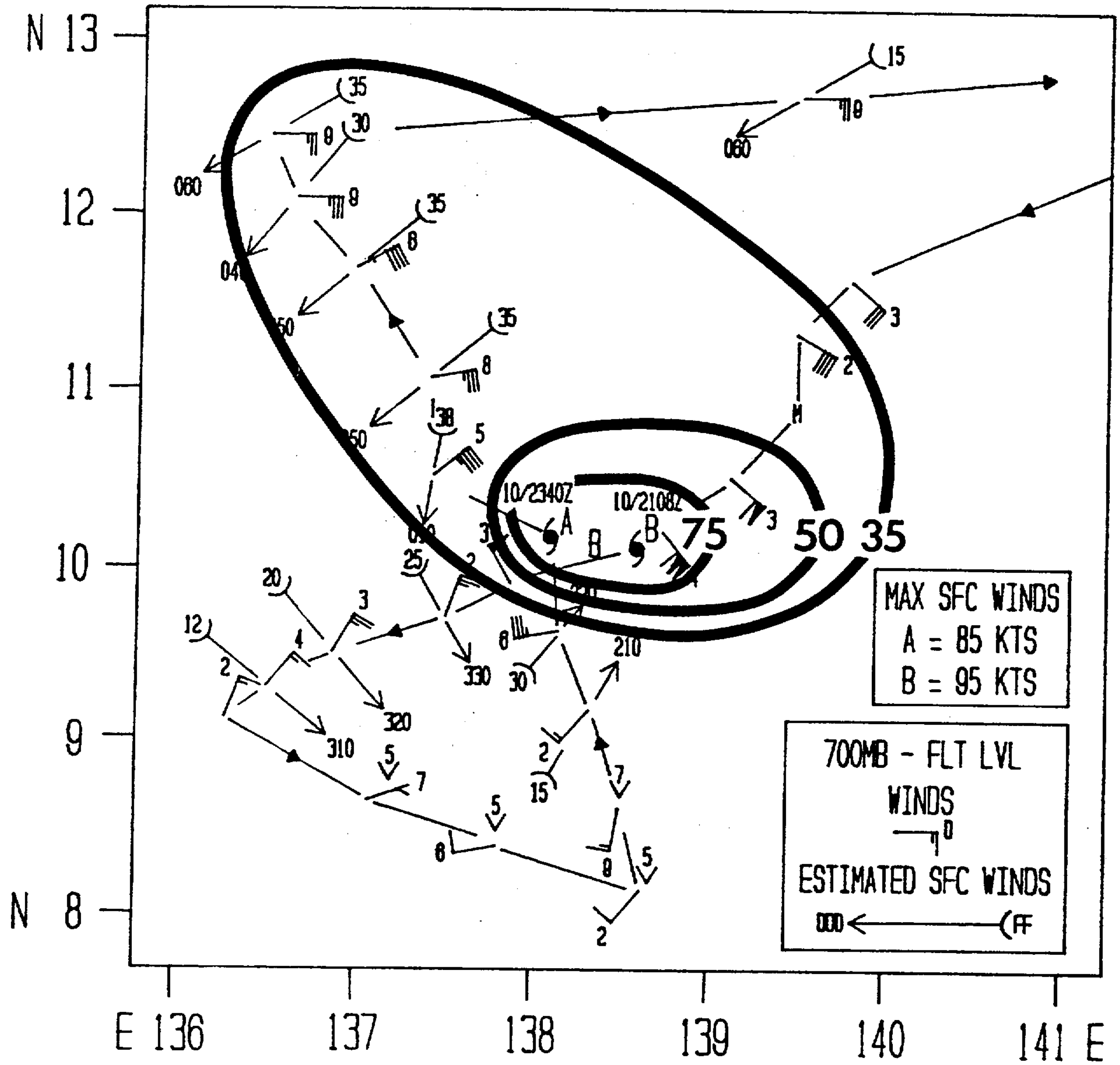


Figure 3-01-1. The 110000Z January aircraft reconnaissance fix mission of Typhoon Orchid (01W) near maximum intensity. Note the tight gradient of surface winds to the south of the vortex center.

Figure 3-01-2. Damage to the Outer-Island School located on the north side of Falalop Island on the Ulithi Atoll. All these buildings sustained some damage while others (dormitories and classrooms) were totally destroyed (Photo courtesy of Mobil Oil Micronesia, Inc.).

Advisory (ABPW PGTW) at 030600Z. Over the next four to five days, this area drifted toward the west and slowly increased in organization and convection until a small ragged central dense overcast (CDO) formed and upper-level outflow improved. A Tropical Cyclone Formation Alert followed at 072130Z and a daylight hours aircraft reconnaissance investigative mission was tasked for the next day. No surface data was available near the system; however, at 080419Z Dvorak satellite intensity analysis of the disturbance estimated maximum sustained surface winds of 25 to 30 kt (13 to 15 m/sec). This prompted JTWC to issue the first warning on Tropical Depression 01W at 081200Z. The next morning, the aircraft investigative mission reported maximum sustained surface winds of 45 kt (23 m/sec). This prompted the upgrade of the system on the third warning (at 090000Z) to Tropical Storm Orchid (01W).

Figure 3-01-3. Corrugated sheet roofing embedded in a coconut log on Falalop Island on Ulithi Atoll. This building material becomes a deadly object to life and property when airborne (Photo courtesy of Mobil Oil Micronesia, Inc.).

There were two unusual aspects of Typhoon Orchid (01W). The first was its small radius of maximum winds. For example, at its peak intensity of 95 kt (49 m/sec) at 110000Z, the radii of 30 kt (15 m/sec) winds were only 45 nm (83 km) in the south semicircle and 140 nm (259 km) in the northwest semicircle (see Figure 3-01-1). The larger wind radius in the northwest semicircle was due partly to interaction with high pressure ridging to the north and the motion vector addition to the winds in the west-northwest, or right front, quadrant. Typhoon Orchid (01W), near maximum intensity, passed directly over the island of Ulithi (WMO 91203). As a result, Ulithi reported surface winds near 100 kt (51 m/sec) and sustained extensive damage (Figures 3-01-2 and 3-01-3). A few hours later, however, Typhoon Orchid passed about 45 nm (83 km) north of the island of Yap (WMO 91413), where surface winds of only 20 to 25 kt (10 to 13 m/sec) and fair skies were reported.

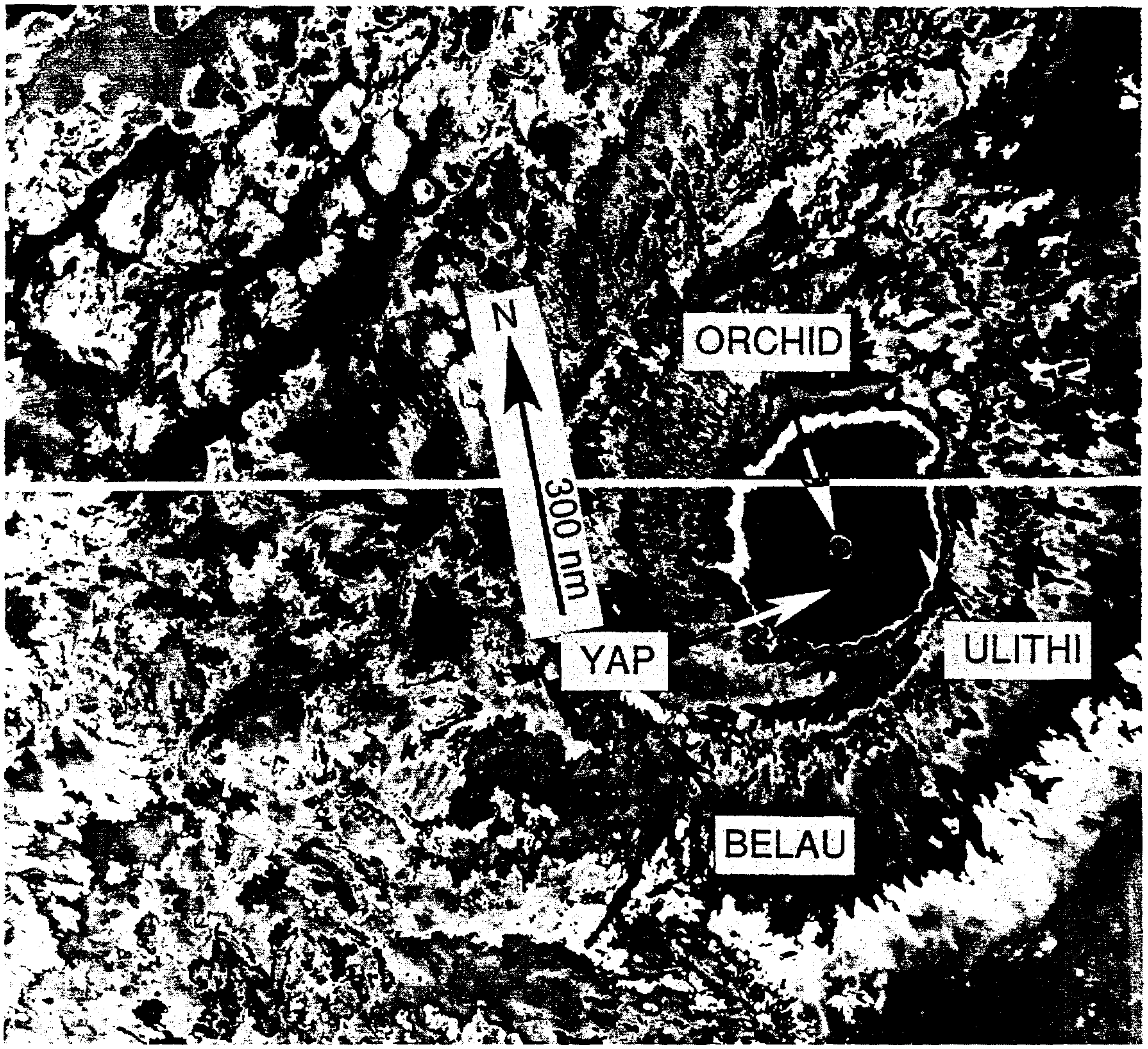


Figure 3-01-4. Enhanced infrared (EIR) imagery of Typhoon Orchid (01W) near maximum intensity. Note the small well-defined eye (102259Z January NOAA infrared imagery).

The second unusual aspect of Typhoon Orchid was the fact that during the two days from 101200Z to 121200Z when Orchid was the most intense (Figure 3-01-4), the Dvorak intensity estimates were 10 to 20 kt (5 to 10 m/sec) higher than the intensity reported by aircraft reconnaissance (Figure 3-01-5).

After reaching maximum intensity, Orchid continued moving northwestward. Between 110000Z and 140000Z (when the last warning was issued), Orchid came under the influence of the strong wintertime low-level northeast monsoonal flow. This, coupled with 200 mb westerly flow aloft, set up a strong vertical shearing environment in which the upper portion of Orchid was displaced toward the east. Once the central convection stripped away, the remaining surface circulation was then steered by the low-level northeast monsoonal flow toward the southwest before dissipating over water. This wintertime shearing situation was a common factor in the end of the last five significant tropical cyclones in November and December of 1986.

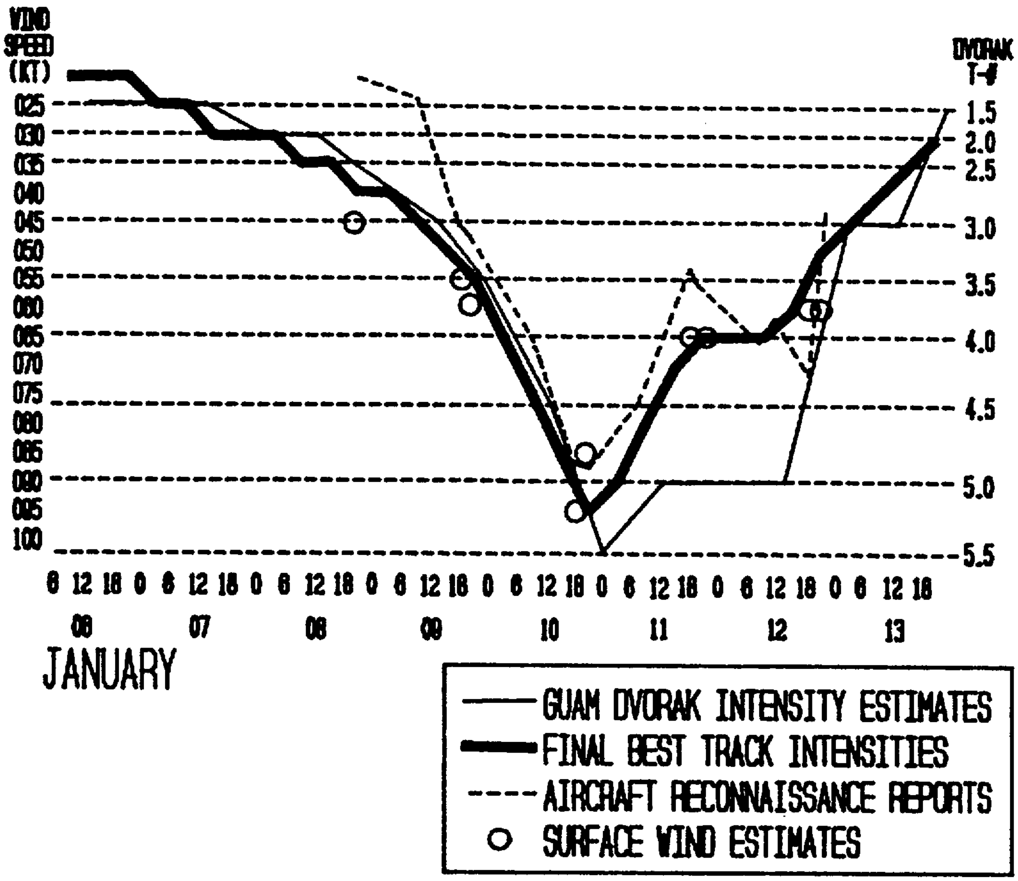
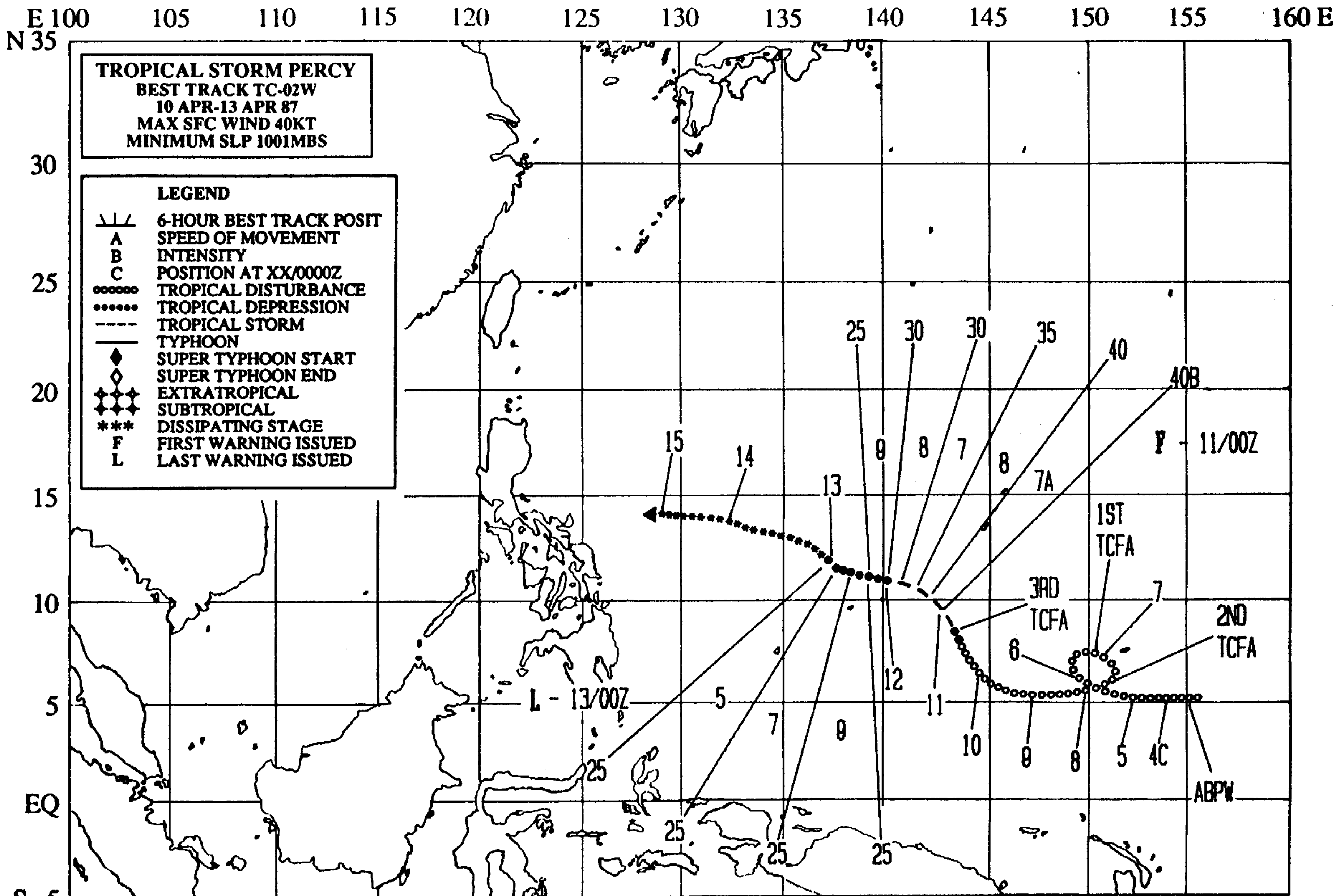


Figure 3-01-5. Plot of intensities obtained for Typhoon Orchid (01W) by aircraft reconnaissance vortex fixes and Dvorak analysis of satellite imagery. Also plotted are the Final Best Track intensities for comparison. Note the higher satellite intensities especially around the time of maximum intensity.


TROPICAL STORM PERCY
BEST TRACK TC-02W
10 APR-13 APR 87
MAX SFC WIND 40KT
MINIMUM SLP 1001MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
F - 11/00Z
L - 13/00Z
1ST TCFA
2ND TCFA
3RD TCFA
ABPW

TROPICAL STORM PERCY (02W)

Percy was the only significant western North Pacific tropical disturbance during April. The vortex struggled to get started, only achieved minimal tropical storm intensity and tenaciously resisted dissipation.

During the first week of April, brisk 30 kt (15 m/sec) northeasterly trades clashed with a low-latitude westerly surge associated with a tropical disturbance in the southern hemisphere. This created an area of cyclonic rotation in the low-level wind field and slightly lower pressures in the eastern Caroline Islands. The resulting convection was first noted on the Significant Tropical Weather Advisory (ABPW PGTW) for 030600Z April. The slow formation of a cloud system led to the issuance of a Tropical Cyclone Formation Alert (TCFA) at 061800Z. Maximum sustained surface winds, at that time, were estimated to be 25 to 30 kt (13 to 15 m/sec). The TCFA was reissued at 071800Z because the area had increased in organization, although the overall convection decreased. By 081800Z, the mid- to upper-level winds over the system increased and the second TCFA was cancelled.

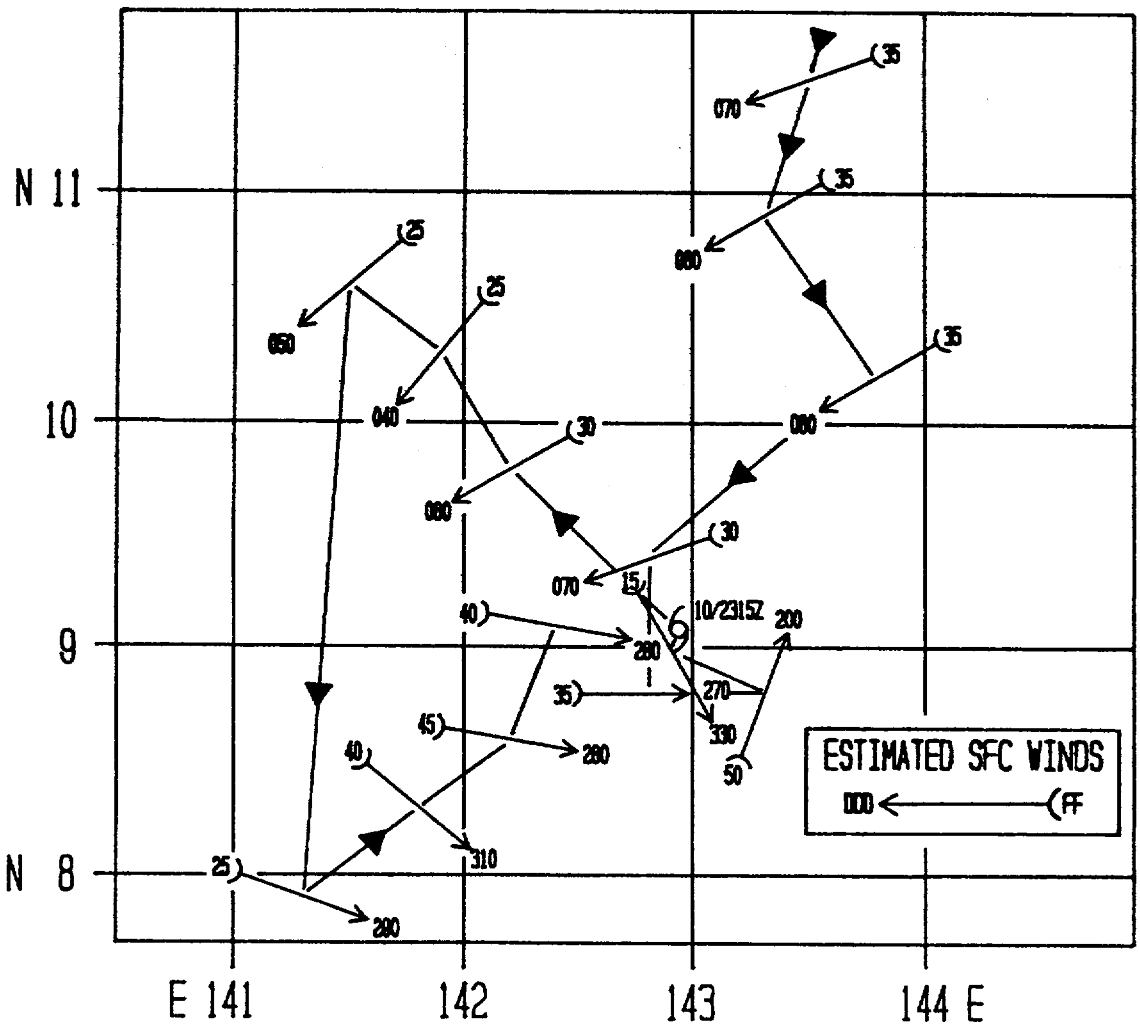


Figure 3-02-1. Plot of aircraft reconnaissance data from the third mission into Tropical Storm Percy (02W) shows increasing surface winds near the center.

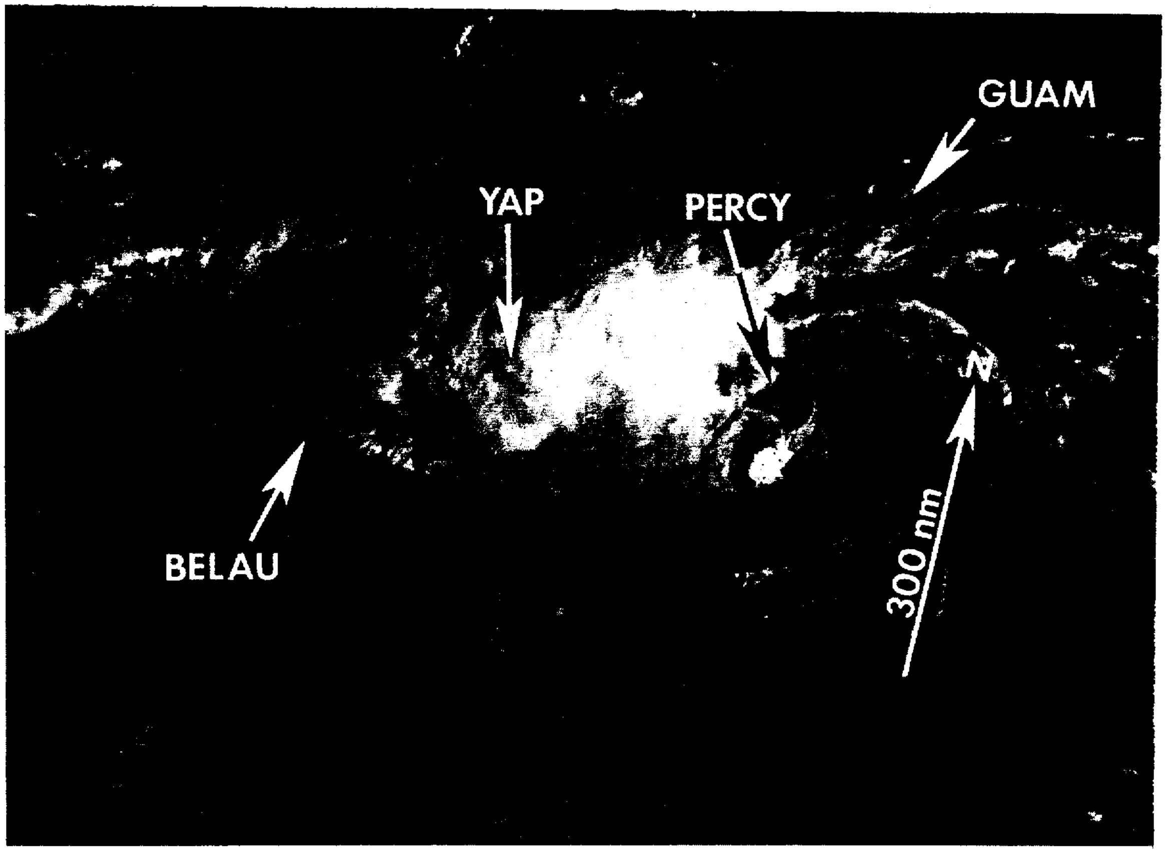


Figure 3-02-2. Tropical Storm Percy (02W), while southwest of Guam, showing an exposed low-level circulation center (110022Z April DMSP visual imagery).

However, the weakened disturbance continued to drift slowly westward for the next three days and possessed fair potential for significant development. By 101407Z the convection and organization had again improved, and the vertical wind shear on the system decreased sufficiently to justify the issuance of a third TCFA. Satellite intensity analysis (Dvorak, 1984) estimated maximum surface winds of 25 kt (13 m/sec) at that time, however, an aircraft daylight investigative mission flown on the morning of the 10th produced unexpected results.

Enroute to the circulation, the aircraft reported gradually increasing flight-level winds (1500 ft (457 m)) and observed surface winds from 30 kt (15 m/sec) near Guam to 40 kt (21 m/sec). Upon reaching the expected location of the low-level cyclonic circulation, the Aerial Recon- naissance Weather Officer (ARWO) reported flight-level winds of 56 kt (29 m/sec) and surface winds of 50 kt (26 m/sec) at 102325Z. The center location was consistent with the increasing surface winds encountered enroute (Figure 3-02-1); however, the magnitude of the winds were inconsistent with the minimum sea-level pressures (MSLPs) enroute (1010 mb to 1003 mb) and at the circulation center (1001 mb). Dvorak satellite intensity analysis at 110022Z estimated 25 kt (13 m/sec) surface winds (Figure 3-02-2). This was more consistent with the extrapolated MSLPs. According to Atkinson and Holliday (1977), an environmental MSLP of near 1012 mb, together with maximum sustained surface winds of 50 kt (26 m/sec) usually implies a central MSLP of about 987 mb. After the aircraft reconnaissance flight-level wind observations, were double-checked, Tropical Depression 02W was upgraded to a tropical storm.

Aircraft reconnaissance was available again at 112100Z. Flight-level and surface winds were much lighter than observed 24-hours earlier. Values ranged from 20 to 32 kt (10 to 16 m/sec) at flight level enroute to the early fix at 112120Z, and 15 to 20 kt (8 to 10 m/sec) prior to the primary fix at 112354Z. The Dvorak satellite intensity analysis at 122304Z estimated 25 kt (13 m/sec) maximum sustained surface winds. As a result, the final warning on Tropical Storm Percy (02W) followed at 130000Z. Percy's circulation persisted as an exposed low-level center through the 15th, with the remaining convection located well to the northeast and southwest (Figure 3-02-3). The residual low-level eddy, that remained, finally dissipated near northern Luzon on the 19th of April.

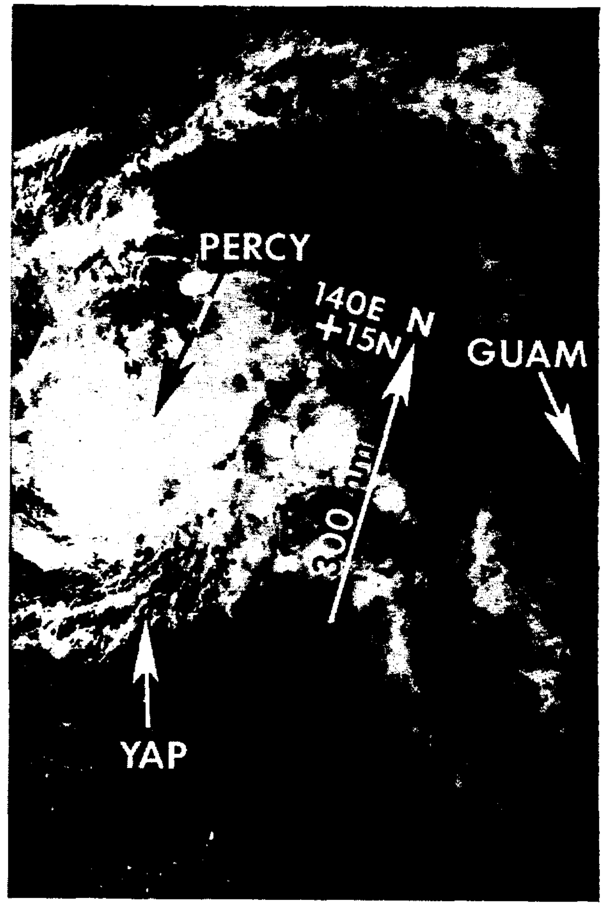
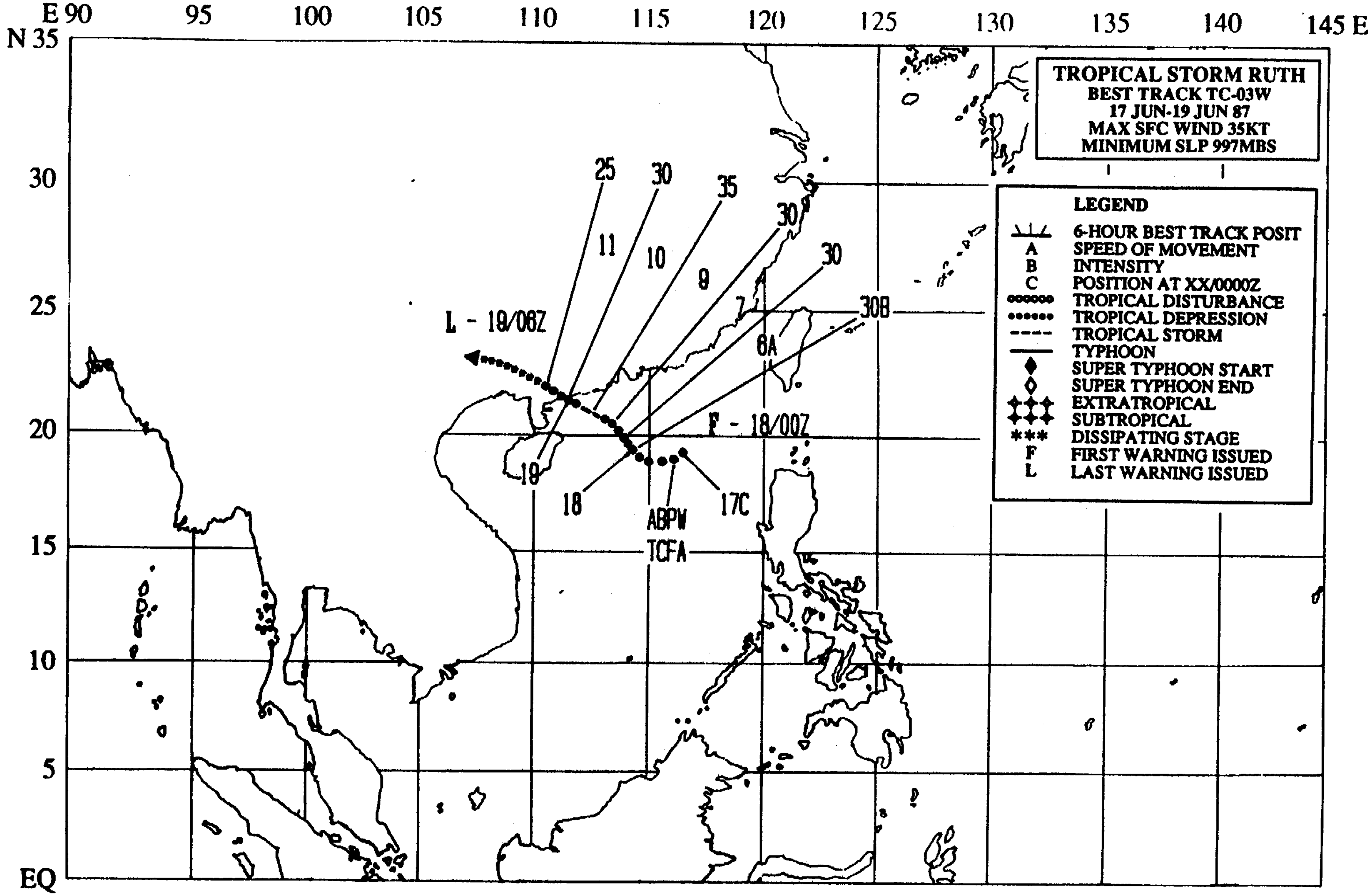


Figure 3-02-3. Tropical Storm Percy (02W) in the Philippine Sea just before the final warning was issued (122341Z April DMSP visual imagery).


TROPICAL STORM RUTH
BEST TRACK TC-03W
17 JUN-19 JUN 87
MAX SFC WIND 35KT
MINIMUM SLP 997MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 19/06Z
F - 18/00Z
ABPW
TCFA
17C
18
19
6A
30B
25
30
35
30
30
11
10
9
7
E 90
95
100
105
110
115
120
125
130
135
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N 35
30
25
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EQ

TROPICAL STORM RUTH (03W)

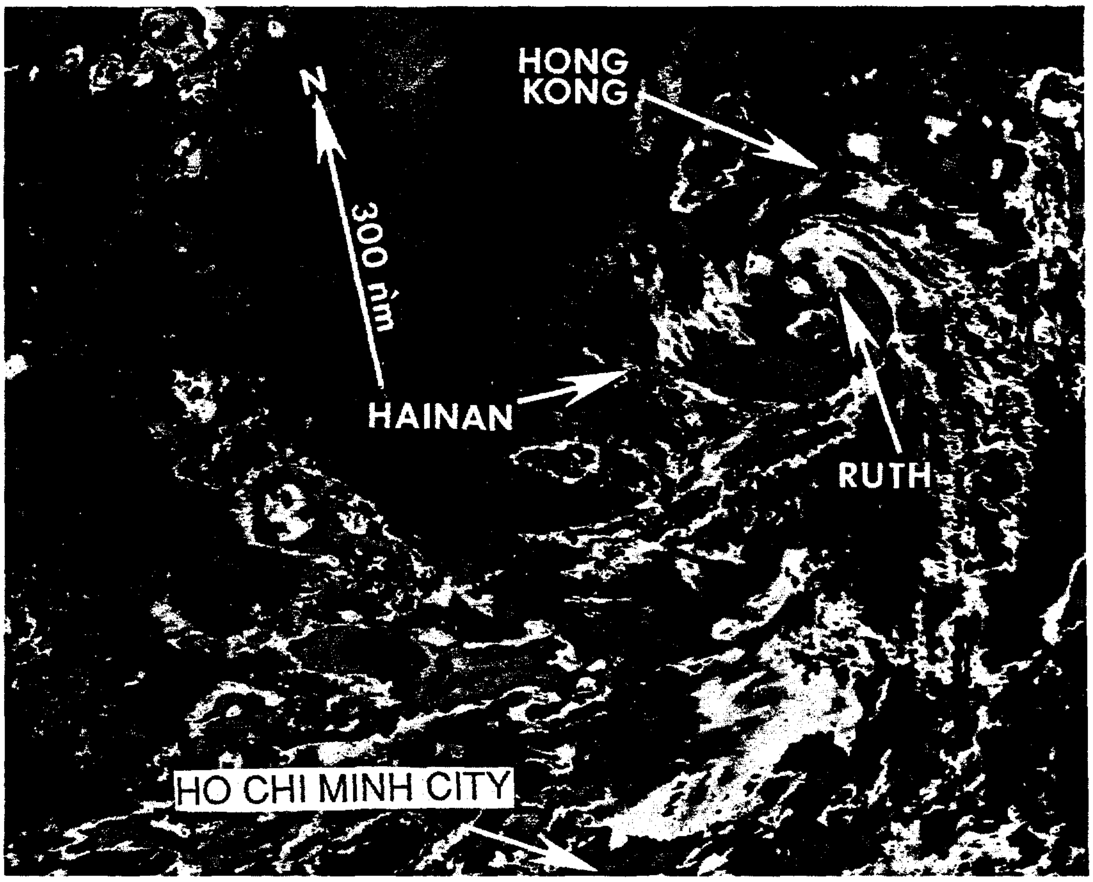
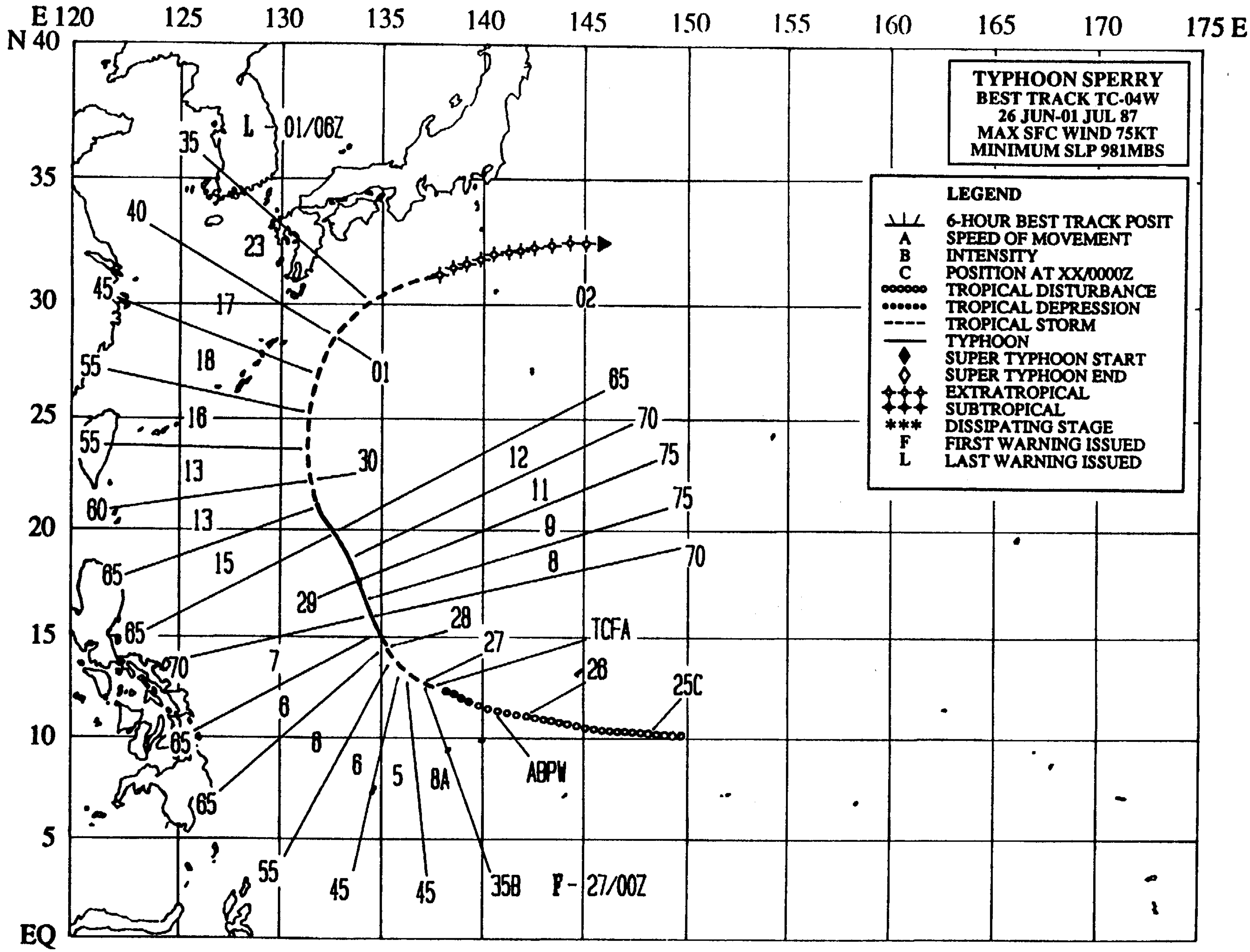


Figure 3-03-1. Tropical Storm Ruth was a short-lived tropical cyclone. Only six warnings were issued on the system before it moved inland and dissipated over southern China. It began as a monsoon depression 240 nm (444 km) southeast of Hong Kong over the South China Sea. Early on 17 June, convection consolidated into convective bands prompting its mention on the Significant Tropical Weather Advisory (ABPW PGTW) at 0600Z as having good potential for development. As a result, JTWC issued a Tropical Cyclone Formation Alert, valid at the same time, because satellite imagery indicated upper-level anticyclonic outflow was becoming established. JTWC issued the first warning on Tropical Depression 03W at 180000Z, after synoptic reports indicated surface pressures in the area had dropped significantly overnight from 1001 mb to 995 mb. The initial forecast tracks indicated the system would move northwestward, but subsequent forecasts gradually shifted the track further west as the subtropical ridge east of Ruth began ridging slowly westward across southern China. The system was upgraded to tropical storm intensity at 181800Z based upon a Dvorak intensity estimate of 35 kt (18 m/sec) maximum sustained surface winds associated with convective bands which were wrapped halfway around the center (see image above). Ruth was downgraded to a tropical depression on the fifth warning as it interacted with the southern coast of China. Hong Kong (WMO 45005) radar reports were excellent and proved instrumental in accurately tracking this tropical cyclone for a day before it made landfall. Ruth dissipated within eighteen hours of moving inland, causing little damage and no known deaths (181138Z June DMSP infrared imagery).


TYPHOON SPERRY
BEST TRACK TC-04W
26 JUN-01 JUL 87
MAX SFC WIND 75KT
MINIMUM SLP 981MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120 125 130 135 140 145 150 155 160 165 170 175 E
N 40 35 30 25 20 15 10 5 EQ
L - 01/06Z
F - 27/00Z
TCFA
ABPW
25C
02
01

TYPHOON SPERRY (04W)

Typhoon Sperry was the second tropical cyclone to reach typhoon intensity and also the second "midget" typhoon in 1987. It was also the season's first to enter the mid-latitude westerlies and recurve toward the northeast.

The tropical disturbance that eventually developed into Typhoon Sperry was first detected by synoptic data on 24 June as a broad, weak surface circulation in the western extension of the monsoon trough 200 nm (370 km) to the northwest of the island of Truk in the eastern Caroline Islands. The convection in this area appeared to be random. At the same time, a second area of disorganized convection was developing 210 nm (389 km) east of the island of Enewetak in the Marshalls. To the north and east, a Tropical Upper-Tropospheric Trough (TUTT) extended from Wake Island southwestward to just northeast of Guam. The broad subtropical ridge dominated the low-level flow pattern in the northwest Pacific. Although the two convective areas consolidated on 25 June, the resultant disturbance still struggled for two more days before reaching tropical storm intensity. The most probable cause for this slow intensification was the close proximity of a TUTT low (Sadler, 1979) to the northeast. This low aloft, in conjunction with the lower

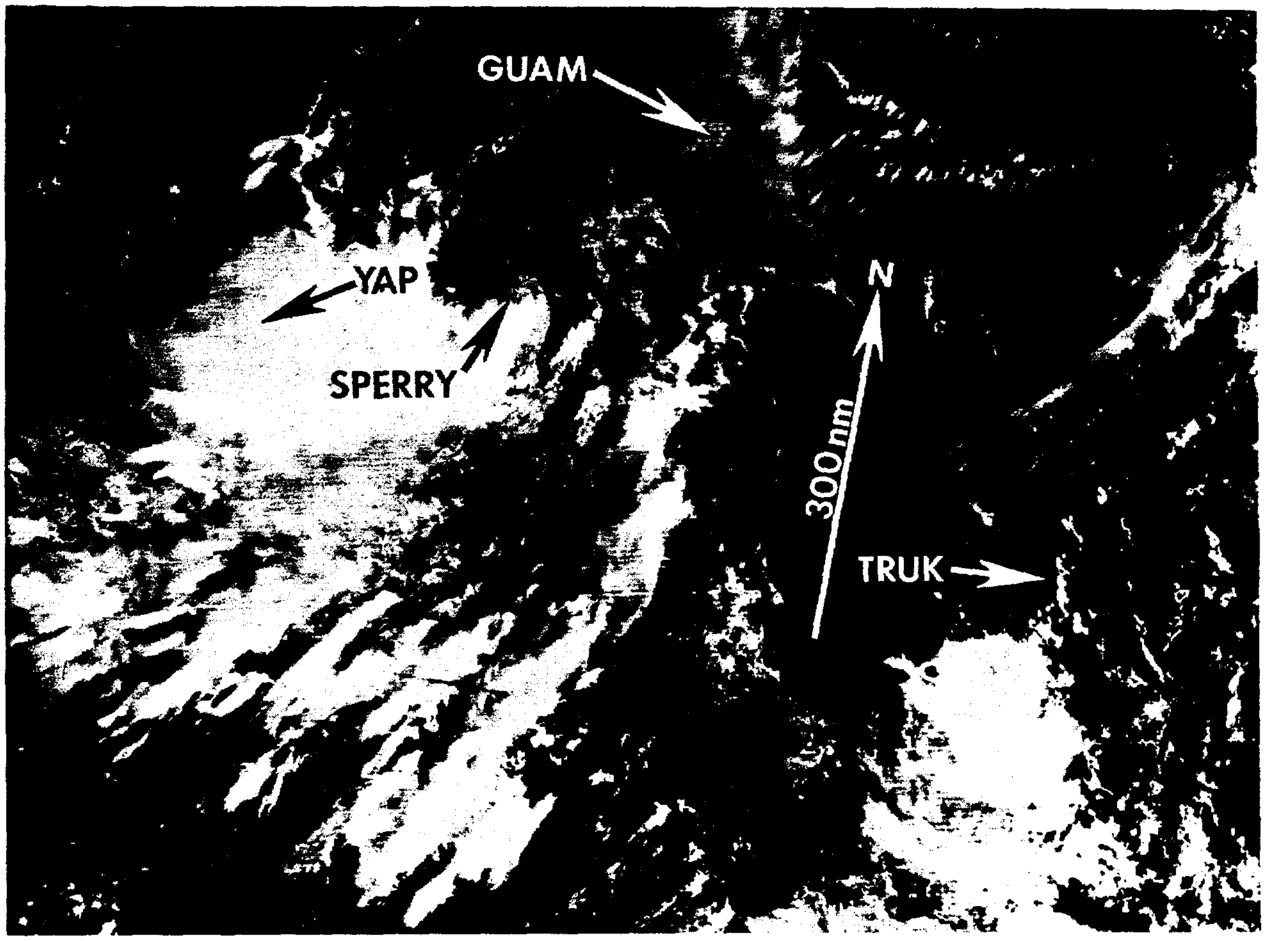


Figure 3-04-1. Visual satellite imagery showing the tropical disturbance that would later develop into Typhoon Sperry. Note the low-level circulation center displaced to the northeast of the main convection (252347Z June DMSP visual imagery).

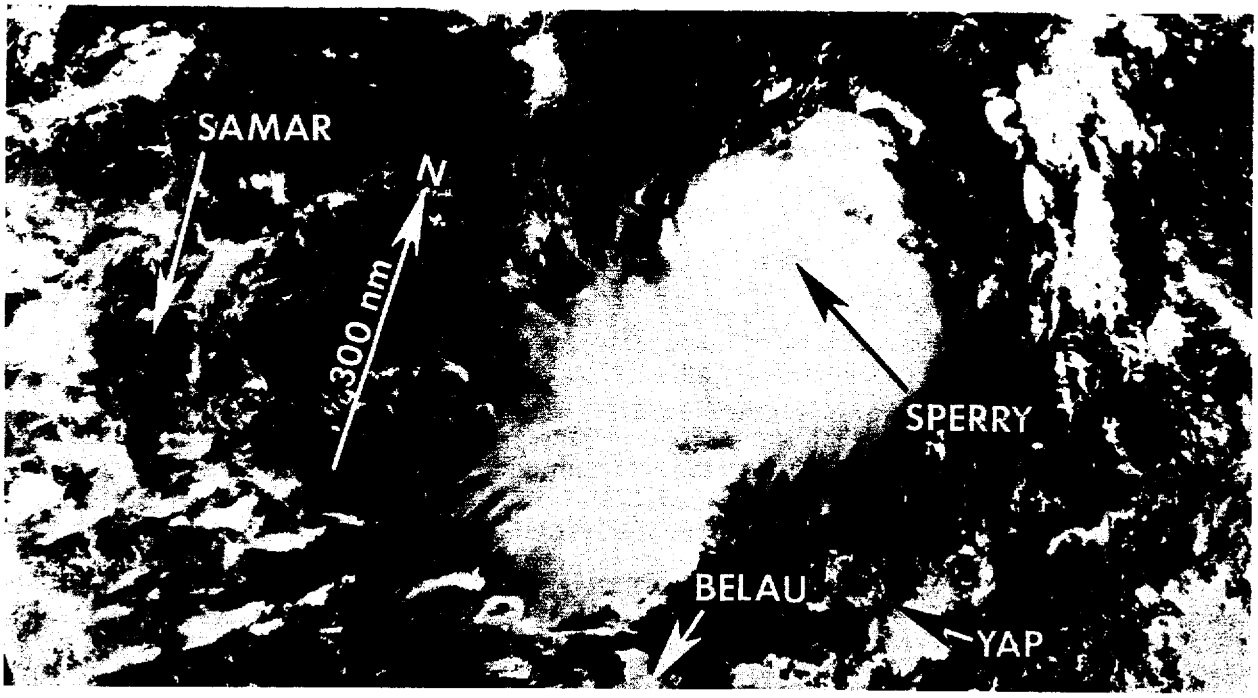


Figure 3-04-2. Typhoon Sperry with an intensity of 65 kt (33 m/sec) just prior to peaking (280047Z June DMSP visual imagery).

tropospheric subtropical ridge, created an area of strong vertical wind shear (Figure 3-04-1).

The low-level disturbance drifted west-northwestward for the next several days. At that point, the separation between the TUTT low, or cell, and the low-level tropical disturbance to the southwest remained static. However, an interesting change occurred aloft. By 251200Z a plume of dense cirrus, associated with a 55 kt (28 m/sec) wind maximum entering the western side of the upper cold low from the north, moved southward. Within eighteen-hours the cirrus plume had plunged into the southwest portion of the TUTT cell. The cell responded. The circulation within the core of the upper low tightened up and became more symmetrical. This, in turn, reduced the vertical wind shear across the system and as a result, the central convection started to increase within the low-level disturbance again. Earlier (at 241200Z), the Navy Operational Global Atmospheric Prediction System upper-air prognoses, had correctly forecast this lessening of vertical shear. The new convection was initially mentioned on the 260600Z Significant Tropical Weather Advisory (ABPW PGTW).

Based upon satellite intensity analysis (Dvorak,1984) of satellite imagery between 1500Z and 2100Z on the 26th, analysts of Detachment 1, 1st Weather Wing estimated that the disturbance had 30 kt (15 m/sec) surface winds, based on more organized and intense convection. The satellite reconnaissance inputs prompted the issuance of a Tropical Cyclone Formation Alert (TCFA) at 262230Z. An aircraft reconnaissance investigative mission was requested for the following day. At the time of the TCFA, synoptic data was not available near the center of the disturbance. However, surface data on the periphery of the disturbance implied that at least a 10 kt (5 m/sec) low-level circulation was present. The only reported stronger wind was the gradient-level (3000 ft (914 m)) report at Yap (WMO 91413), which increased from 10 kt (5 m/sec) at 261200Z to 15 kt (8 m/sec) at 270000Z as the disturbance passed northeast of the island on the 26th.

The first warning on Tropical Storm

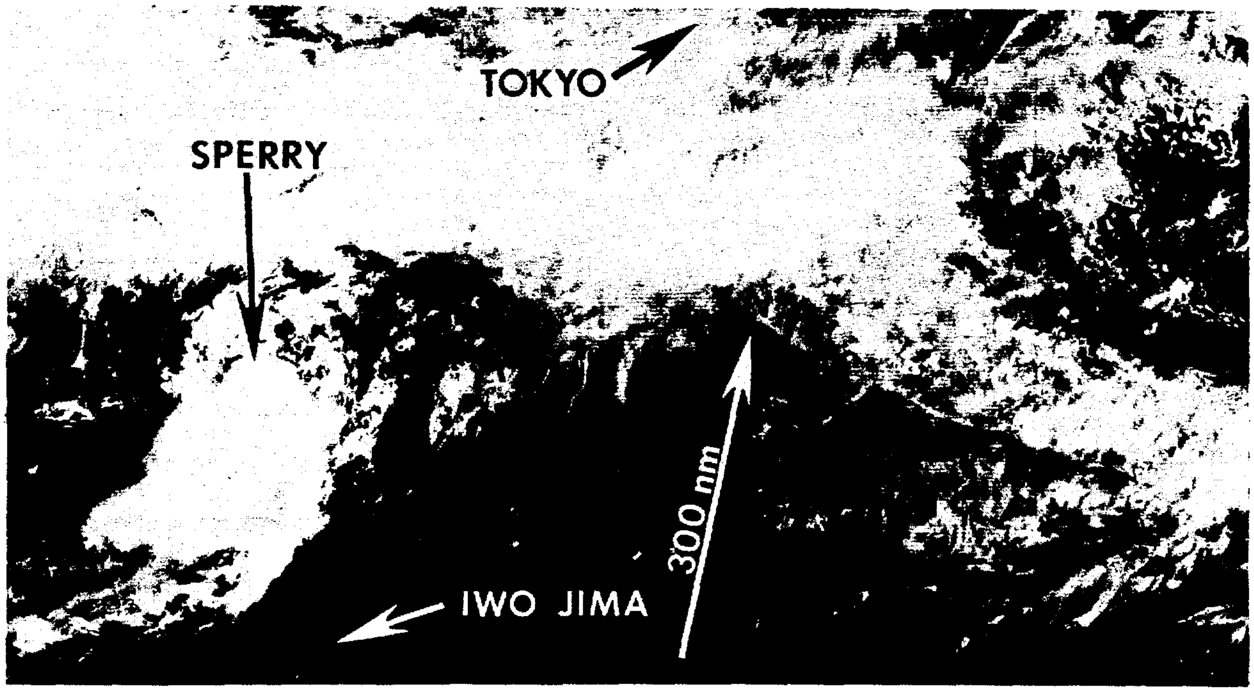


Figure 3-04-3. Sperry interacting with a frontal boundary south of Japan (302345Z June DMSP visual imagery).

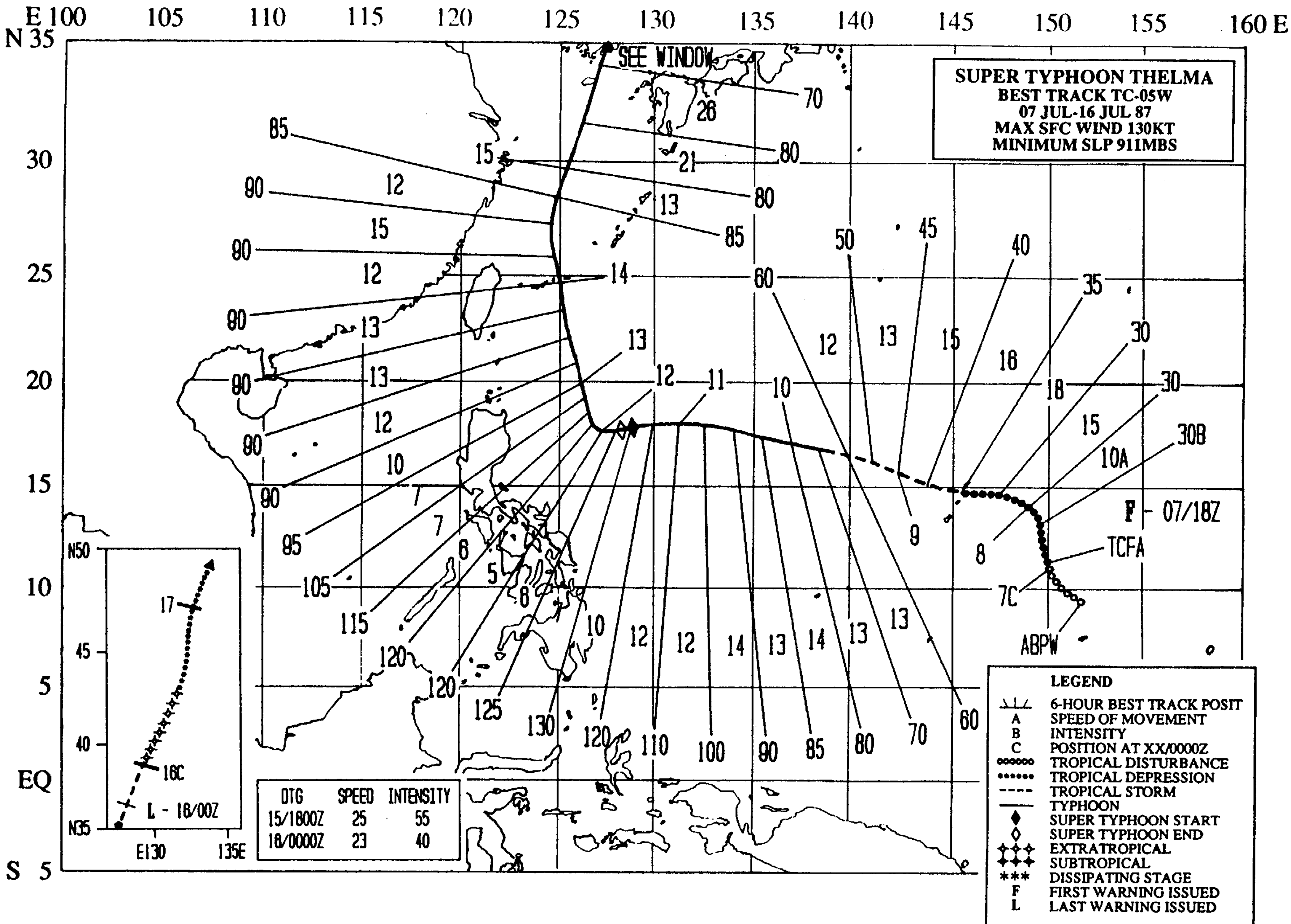
Sperry was issued on the 27th, valid at 0000Z, after visual satellite imagery showed that a central dense overcast and 35 kt (18 m/sec) maximum sustained surface winds were present. Aircraft reconnaissance later in the day located a 1001 mb circulation center with 40 kt (21 m/sec) maximum sustained surface winds, extending out to 50 nm (93 km) southeast of the center. Initial forecasts called for Sperry to follow an around-the-ridge scenario and recurve. This forecast philosophy proved to be correct.

Sperry attained typhoon intensity 24-hours later at about 280000Z. The Aerial Reconnaissance Weather Officer reported Sperry as very compact, with 70 kt (36 m/sec) maximum sustained surface winds surrounding a small, circular 15 nm (28 km) diameter eye. The eye was open to the north and had a minimum sea-level pressure of 983 mb. Sperry developed a ragged eye while moving northwestward under the influence of the mid-level steering flow around the western periphery of the subtropical ridge. Its intensity peaked at 75 kt (39 m/sec) between 281200Z and 281800Z (Figure 3-04-2). This set the stage for Typhoon Sperry's final phase.

By 290000Z, with a frontal boundary and associated mid-latitude trough moving eastward across southern Japan, a recurvature scenario appeared most probable. JTWC incorporated this into the warnings and called for recurvature in 48-hours. Sperry came under the influence of the mid-latitude westerlies and recurved passing 175 nm (324 km) to the east of the island of Okinawa in the Ryukyu Island chain.

After recurvature, Sperry started a gradual acceleration toward the northeast. By 1800Z on the 30th, the intense central convection became displaced south-southwest of the low-level circulation center. A steady decrease in cloud organization and intensity followed. Figure 3-04-3 shows the proximity of the frontal boundary and effect of the strong vertical wind shear on the remaining convection. The final warning was issued as Sperry transitioned to extratropical at 010600Z.

After completing extratropical transition, the low-level circulation drifted eastward embedded in the frontal boundary. There were no reports of lives lost or damage to shipping due to Typhoon Sperry.


SUPER TYPHOON THELMA
BEST TRACK TC-05W
07 JUL-16 JUL 87
MAX SFC WIND 130KT
MINIMUM SLP 911MBS
SEE WINDOW
F - 07/18Z
TCFA
7C
ABPW
10A
30B
L - 16/00Z
16C
17
N50
45
40
N35
E130
135E
DTG SPEED INTENSITY
15/1800Z 25 55
16/0000Z 23 40
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
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15
10
5
EQ
S 5

SUPER TYPHOON THELMA (05W)

Thelma was the first of four significant tropical cyclones to develop in July and the first super typhoon of 1987. Forecasting the timing and location of recurvature presented a problem for JTWC. After recurvature, Thelma slammed into Korea causing extensive damage and the loss of many lives.

As a tropical disturbance, Thelma's initial intensification was slow, but once the system became organized it developed at very near the normal Dvorak rate (Dvorak, 1984) of one "T-number" per day from 25 to 130 kt (13 to 67 m/sec). Thelma originated in the monsoon trough as a broad area of convection with slight curvature. Dvorak analysis estimated an intensity of 25 kt (13 m/sec), while synoptic data indicated a cyclonic surface circulation was present along with upper-level divergence. As a result, the area was mentioned on the Significant Tropical Weather Advisory (ABPW PGTW) at 060600Z. Over the next eight hours, the amount of convection and its organization increased. In addition, an aircraft reconnaissance investigative mission early on the 7th was able to close off the low-level circulation center and found a minimum sea-level pressure (MSLP) of 1003 mb. They also reported maximum sustained surface winds of 20 kt (10 m/sec). At 070300Z, JTWC issued a Tropical Cyclone Formation Alert.

The first warning on Tropical Depression 05W was issued at 071800Z when the system demonstrated a steady increase in convection and organization, and satellite intensity analysis estimated 30 kt (15 m/sec) sustained surface winds. The forecast philosophy called for movement toward the north for 24-hours through a weakness in the 700 mb ridge. The ridge was then expected to strengthen and drive the system toward the west. This did occur, but at speeds nearly triple those forecast.

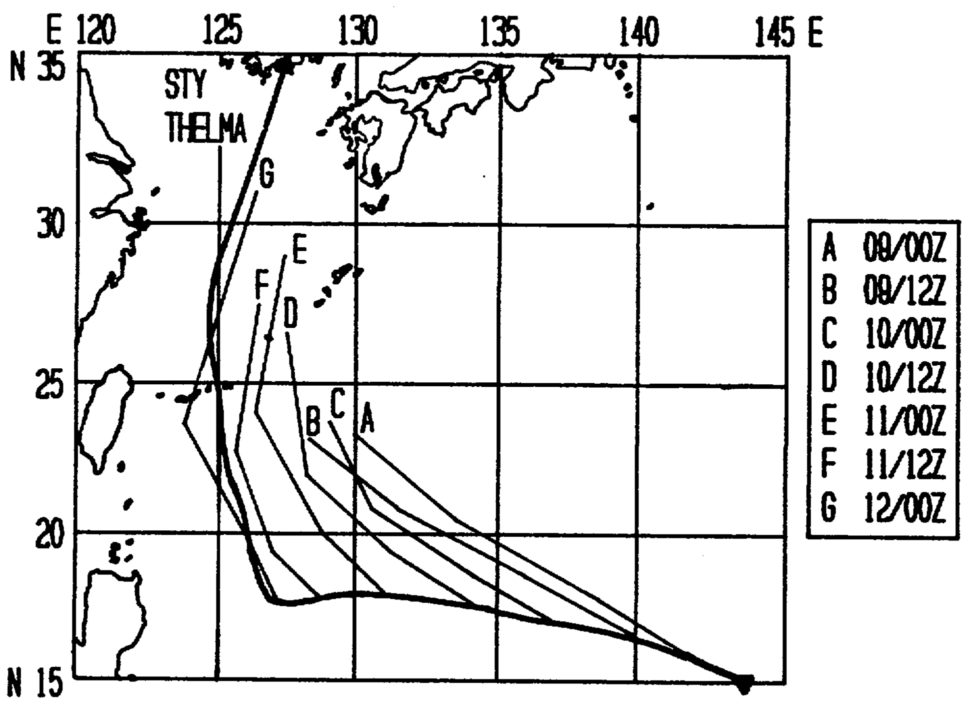


Figure 3-05-1. Plot of OTCM guidance. The OTCM, JTWC's primary dynamic aid, repeatedly indicated recurvature.

Initially, Thelma did not develop as quickly as expected. Once the first warning had been issued on Tropical Depression 05W, the system became broader and less organized. Aircraft reconnaissance scheduled for 080000Z was unable to close off a surface center. Thirteen hours later, the poorly organized system passed about 60 nm (111 km) to the north of Guam. Finally at 090000Z (on warning number six), the system was upgraded to tropical storm intensity. The upgrade was based on aircraft reconnaissance data at 090029Z which reported a MSLP of 996 mb and maximum sustained surface winds of 50 kt (26 m/sec). (Post-analysis indicated that the intensification had most probably occurred 12-hours earlier.)

JTWC's primary aid, the One-Way Interactive Tropical Cyclone Model (OTCM), preferred a northwesterly track or hinted at recurvature in the 48- to 72-hour time frame beginning with the guidance for warning number 3 (080600Z July) (see Figure 3-05-1). Recurvature forecasts started with warning number 3, valid at 080600Z. Although Thelma continued tracking in a westward direction, JTWC mistakenly continued to forecast recurvature for the next 30-hours (spanning six warnings).

At 091200Z, Thelma began developing a banding eye. Warning number 10, valid at 100000Z, upgraded the system to a typhoon. This action was based on the aircraft reconnaissance data at 092138Z and 100011Z that indicated an extrapolated MSLP of 974 mb and estimated maximum sustained surface winds of 80 kt (41 m/sec). Typhoon Thelma reached its maximum intensity at 111200Z, after a 36-hour pressure fall of 66 mb (and a 12-hour pressure fall of 25 mb) down to 911 mb. During this time, Dvorak intensity estimates kept pace from approximately 77 kt (40 m/sec) to approximately 127 kt (65 m/sec). At 111200Z, Thelma became the season's first super typhoon. Afterward, infrared satellite imagery indicated a warming of the cloud tops which indicated that Thelma had peaked in intensity. Satellite

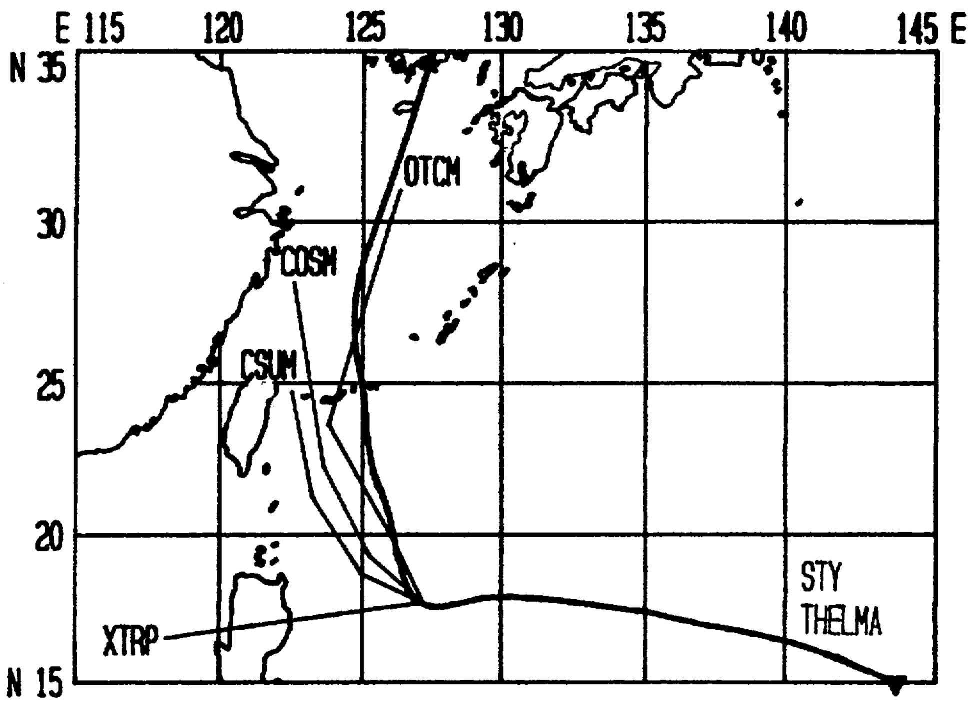


Figure 3-05-2. Plot of statistical aids (CSUM and COSMOS), dynamic numerical aid (OTCM), and persistence (XTRP) along with the final best track at 120000Z, at the point of the abrupt track change toward the north.

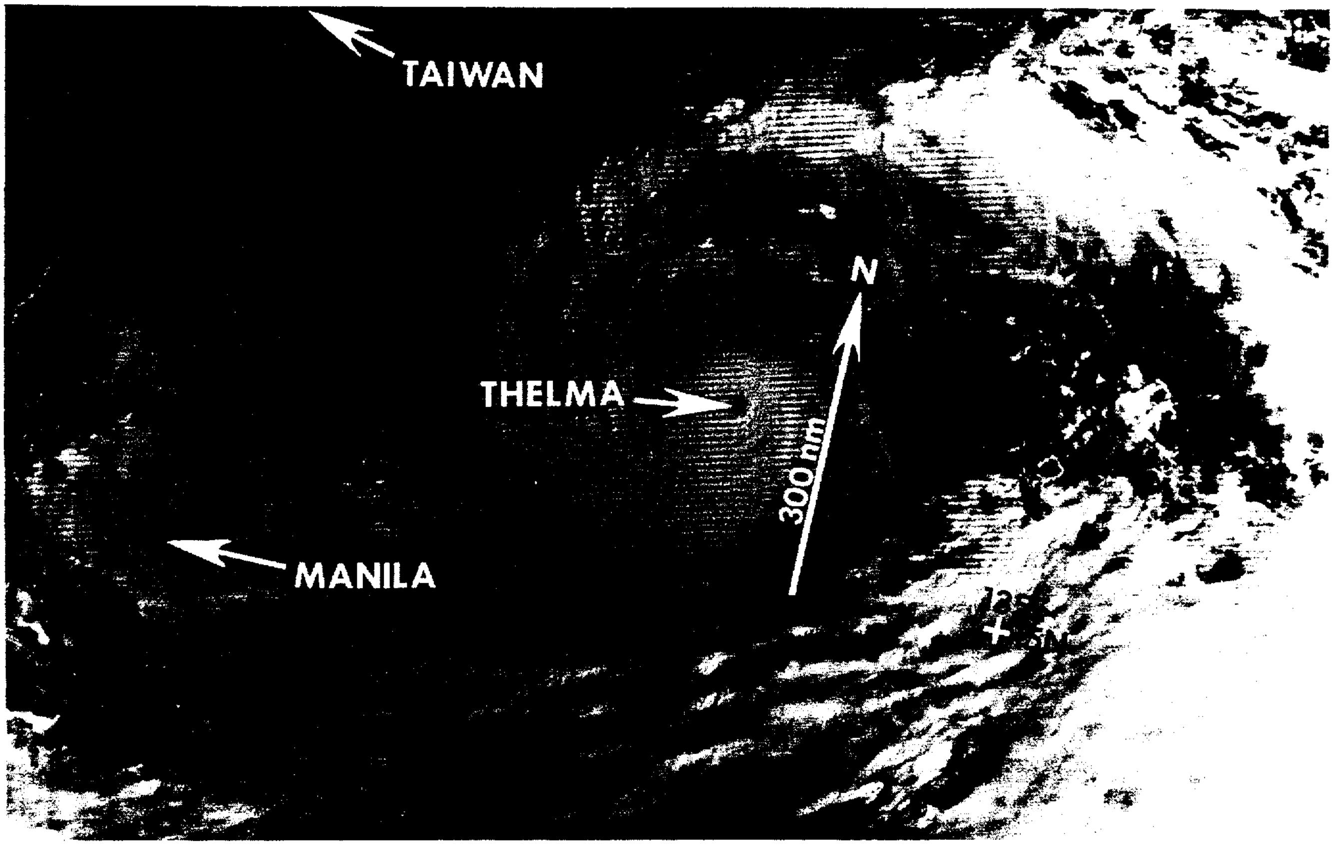


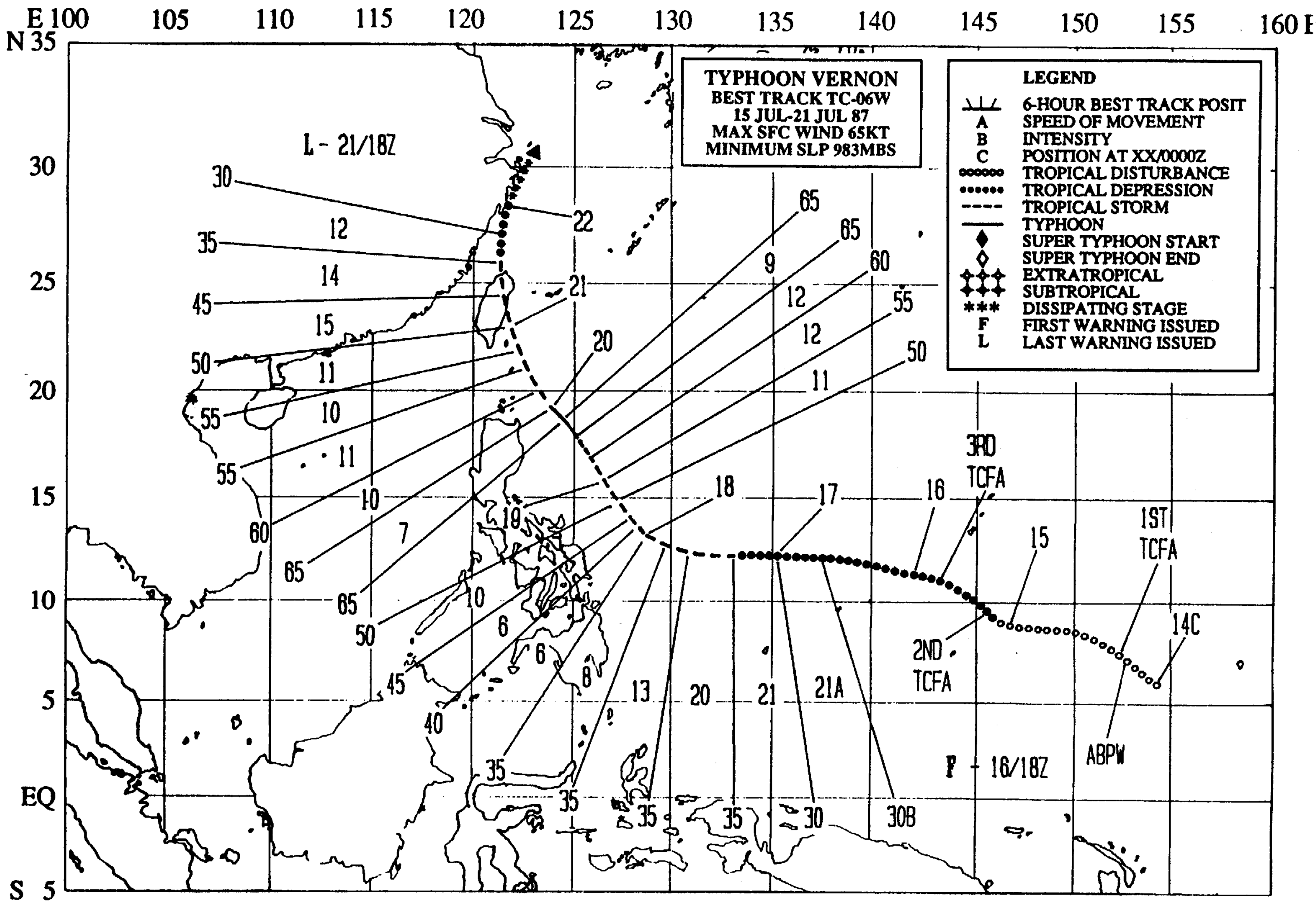
Figure 3-05-3. Visual satellite imagery showing Typhoon Thelma after reaching maximum intensity. Note how the upper-level outflow has become restricted to the north (110632Z July NOAA visual imagery).

imagery also indicated the system's upper-level outflow had become restricted to the north (see Figure 3-05-3). Aircraft reconnaissance at 112353Z found that the eye was open to the north and was becoming elliptical.

Typhoon Thelma began a sharp turn toward the north at 120000Z. Earlier, the dynamic forecast aid OTCM had repeatedly forecast movement toward the north or northwest (see Figure 3-05-2), but the typhoon continued to track westward. By 121200Z, Thelma was heading just west of north and the OTCM guidance was on track.

Even though Thelma's abrupt course change occurred 300 nm (556 km) east of northern Luzon, heavy rains and high seas resulted in at least twelve fatalities in the Philippine Islands. The northerly track took the typhoon west of the island of Okinawa, Japan, and resulted in the evacuation of military aircraft. Commercial airlines also interrupted service, which stranded thousands of air travelers as Thelma passed by.

Finally Typhoon Thelma slammed into South Korea, where widespread flooding caused death and destruction. Floods from Thelma covered thousands of houses, ruptured reservoirs, and destroyed roads, railroad tracks and embankments. News coverage from Korea reported that Thelma killed at least 123 people with 212 additional people listed as missing. The missing were largely seamen and fisherman, who were caught offshore. Officials estimated losses at more than $124 million from damaged or destroyed houses, crops, and water craft.


TYPHOON VERNON
BEST TRACK TC-06W
15 JUL-21 JUL 87
MAX SFC WIND 65KT
MINIMUM SLP 983MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 21/18Z
F - 16/18Z
1ST TCFA
2ND TCFA
3RD TCFA
ABPW
14C
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
S 5

TYPHOON VERNON (06W)

Typhoon Vernon, the second of four significant tropical cyclones to develop in July followed closely on the heels of Super Typhoon Thelma (05W). It was a weak and disorganized system throughout most of its lifetime. As such, initial positioning problems arose in the Philippine Sea due to differences between real-time fix information from radar, satellite and aircraft.

The initial tropical disturbance was first detected in the near-equatorial trough near the island of Truk in the eastern Caroline Islands at 140000Z July and was subsequently listed on the Significant Tropical Weather Advisory (ABPW PGTW) as having poor potential for development into a significant tropical cyclone. However, six hours later a low-level circulation was apparent on visual satellite imagery. The satellite intensity estimate (Dvorak, 1984) was 25 kt (13 m/sec) and a Tropical Cyclone Formation Alert (TCFA) was issued at 140830Z. Convective activity did not increase appreciably for the next two days, but the TCFA was reissued twice due to its persistence. On 161800Z, the first warning was issued for Tropical Depression 06W, based on an estimate of maximum sustained surface winds of 30 kt (15 m/sec) from satellite imagery. The initial forecasts were based on a persistent westward trend with higher than normal speeds of 17 kt (32 km/hr).

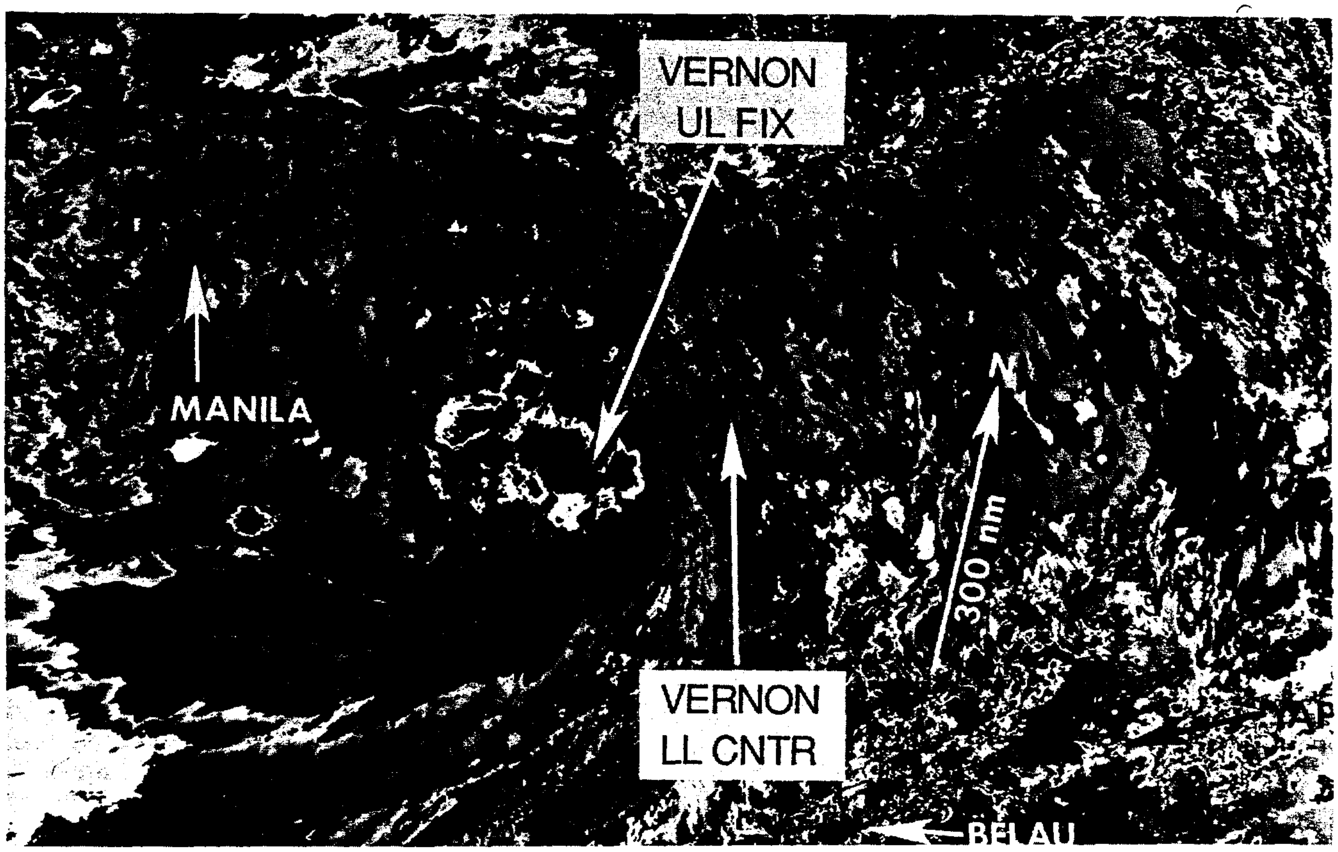


Figure 3-06-1. The area of intense convection as seen on enhanced infrared satellite imagery. This feature was used to fix Vernon during most of the period between 170000Z and the relocation at 181200Z (180042Z July DMSP infrared imagery).

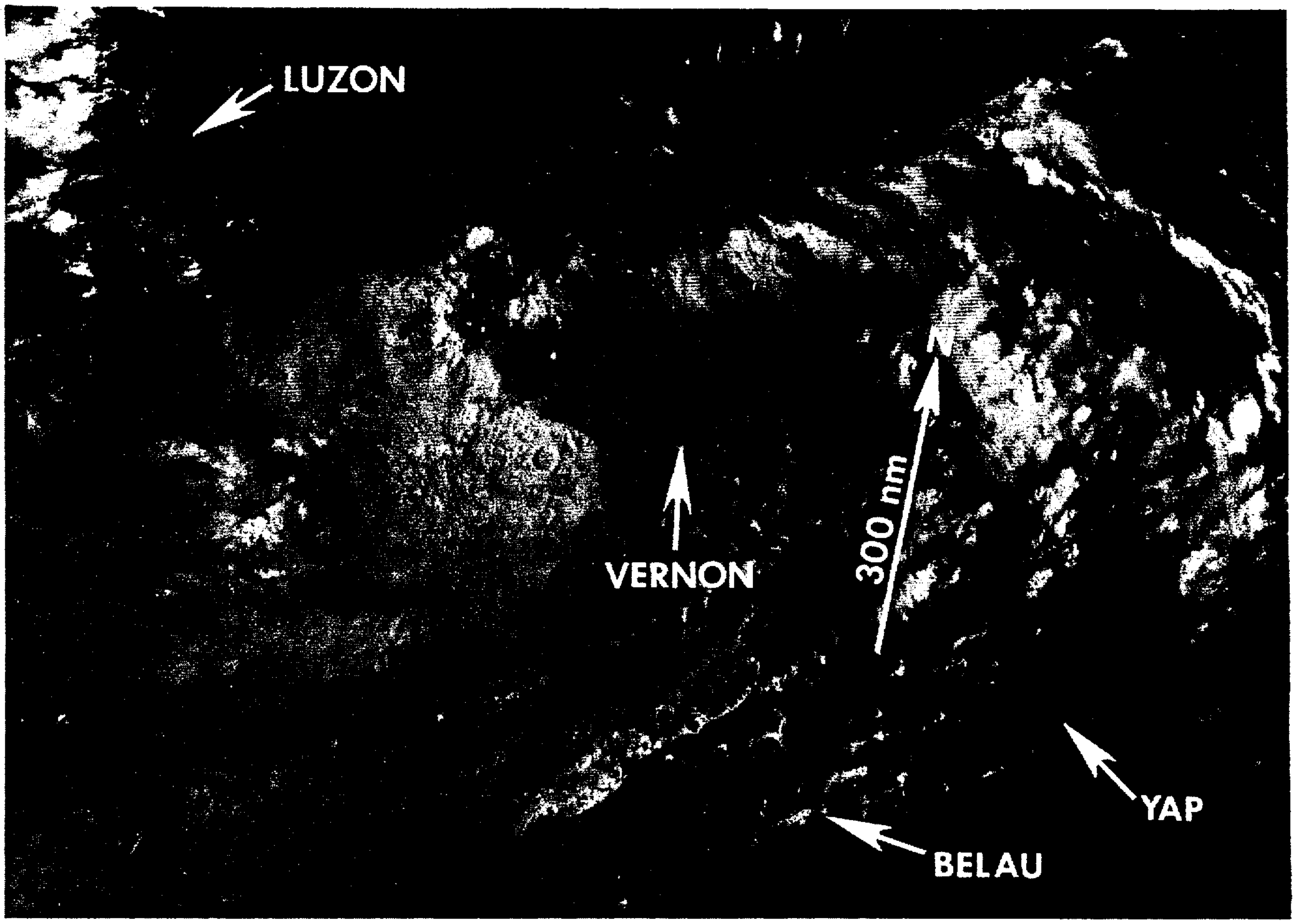


Figure 3-06-2. The exposed low-level circulation center which was mistakenly thought to be a secondary circulation can be seen in the center of the above image. This low-level circulation was not identified as Vernon's main circulation center until 181200Z (180042Z July DMSP visual imagery).

Between 170600Z and 181200Z, satellite fixes and radar reports indicated Vernon had continued to move westward toward the central Philippine Islands. During this time, the most intense area of curved convection remained just east of the Philippines (see Figure 3-06-1) and appeared to be the dominant feature. However, there was also a low-level circulation center northeast of the deep convection which was initially believed to be a secondary circulation center. Figure 3-06-2 shows this exposed low-level circulation center about 180 nm (333 km) northeast of the primary mass of convection at 180042Z.

After the last successful fix at 170224Z July, keeping track of Vernon's weak low-level circulation center became increasingly more difficult. To compound the problem, the radar fixes at two different sites in the Philippine Islands (WMO 98558 and WMO 98447) reinforced the satellite analysis which continued to fix on the main convective mass that was moving towards southern Luzon (see Figure 3-06-3). As a result, Vernon's low-level circulation was not recognized until an exposed low-level circulation was identified by the satellite analyst at 181200Z. Immediately thereafter, Vernon was relocated approximately

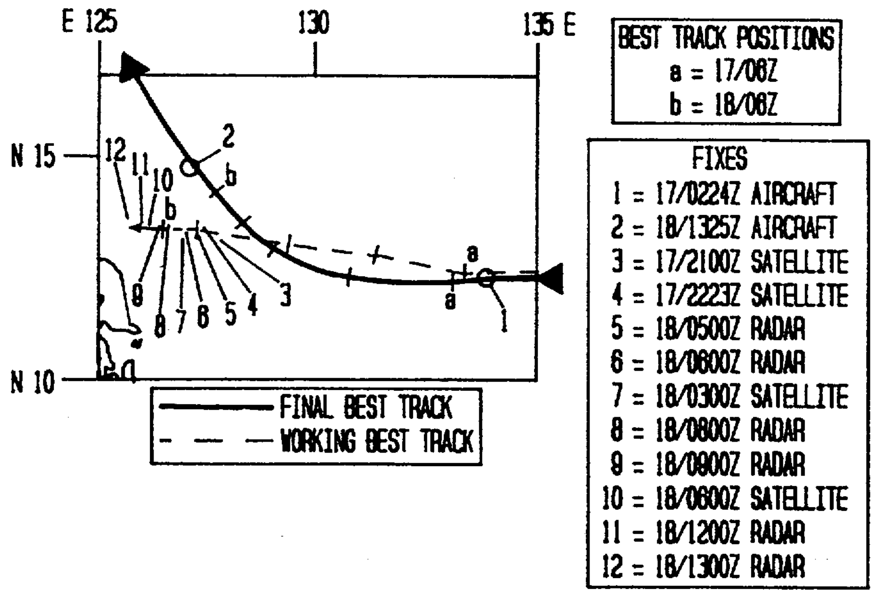


Figure 3-06-3. Typhoon Vernon's best track during the period when the system was relocated. Note that no aircraft fixes were made between 170224Z and 181325Z July. Also note the preponderance of radar fixes and satellite fixes which indicated westward movement when the system was actually moving northwestward (dashed lines). These fixes could not be used in the final best track.

145 nm (269 km) to the north-northeast of the original 180600Z position. This relocation was subsequently verified at 181325Z by the first aerial reconnaissance fix mission in nearly 36-hours.

The Aerial Weather Reconnaissance Officer (ARWO) on the fix mission reported passing a probable vortex center on the inbound leg of the primary fix mission as the aircraft was heading toward the fly-to-point given by the Typhoon Duty Officer. After consulting the Typhoon Duty Officer, it was decided that the satellite and land radar fix position should be investigated. Once there, the ARWO reported rising heights at the 850 mb level and no low-level vortex. The Typhoon Duty Officer then concluded there was only one circulation center, vice multiple vortices. The aircraft crew was then requested to return to the vortex they had passed earlier and investigate it (see Figure 3-06-4). The ARWO subsequently located the vortex and reported a center height of 1363 m at 850 mb.

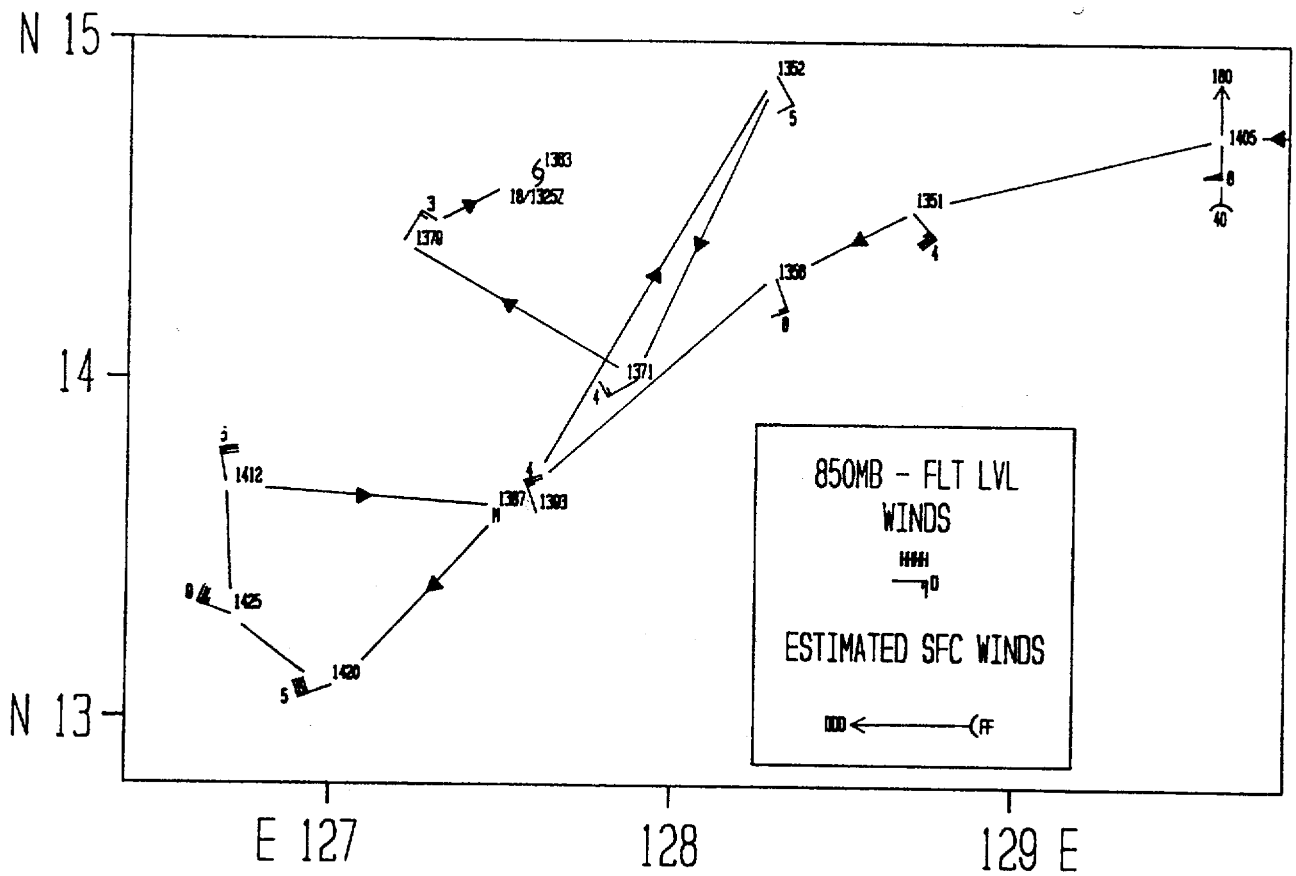


Figure 3-06-4. Plot of the 181325Z July aircraft fix mission which determined the low-level circulation center associated with Vernon.

After the relocation, radar reports from Guiuan Airport (WMO 98558) continued to fix Vernon 170 nm (315 km) south of the aircraft verified position. From synoptic data, there is no evidence that a distinct circulation ever existed separate from Vernon's exposed low-level center. There is also no evidence that the central Philippine Islands ever experienced any significant winds associated with Vernon.

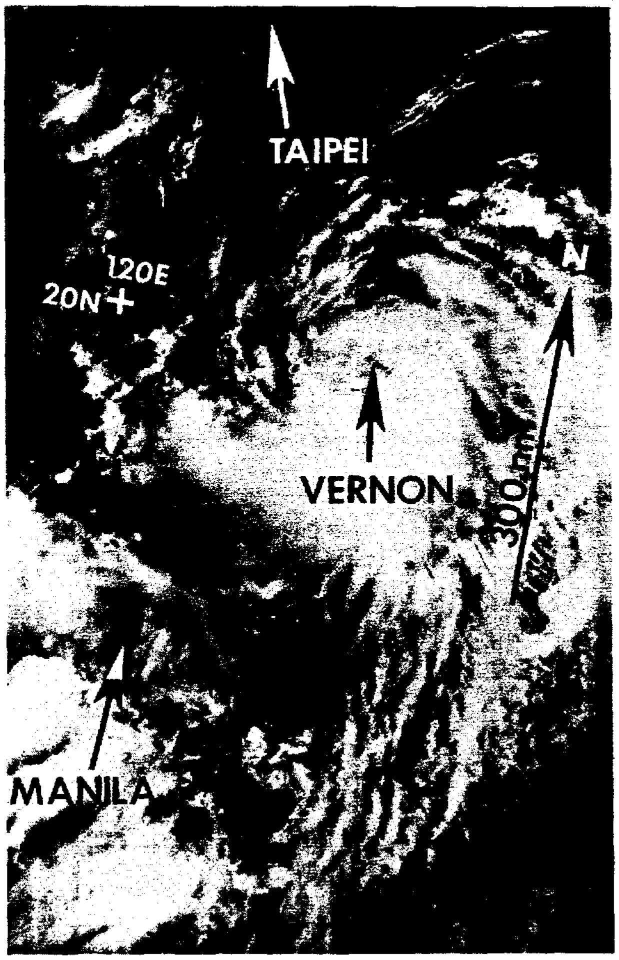


Figure 3-06-5. Typhoon Vernon at its peak intensity of 65 kt (33 m/sec) (200143Z July DMSP visual imagery).

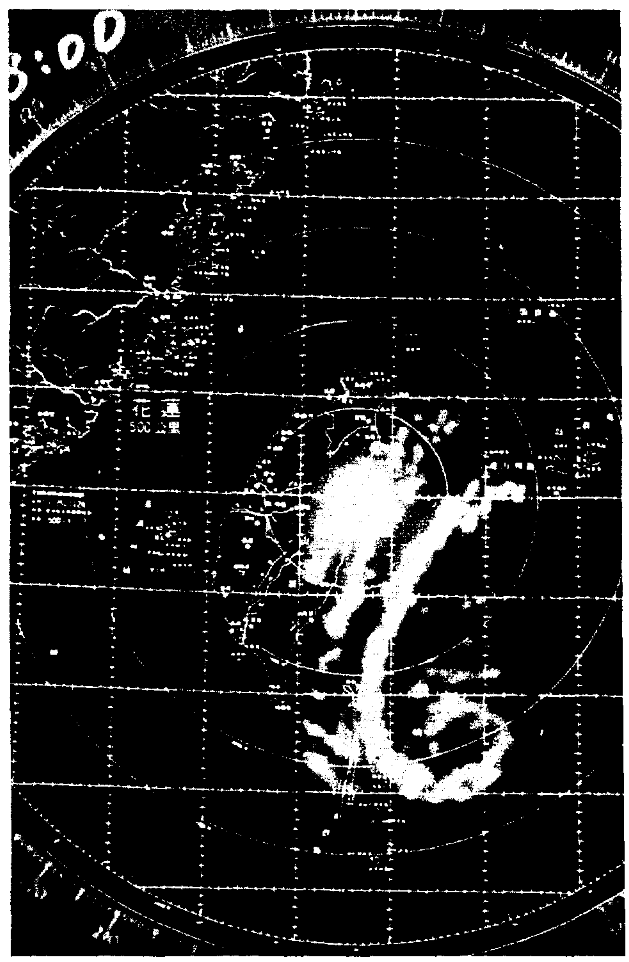
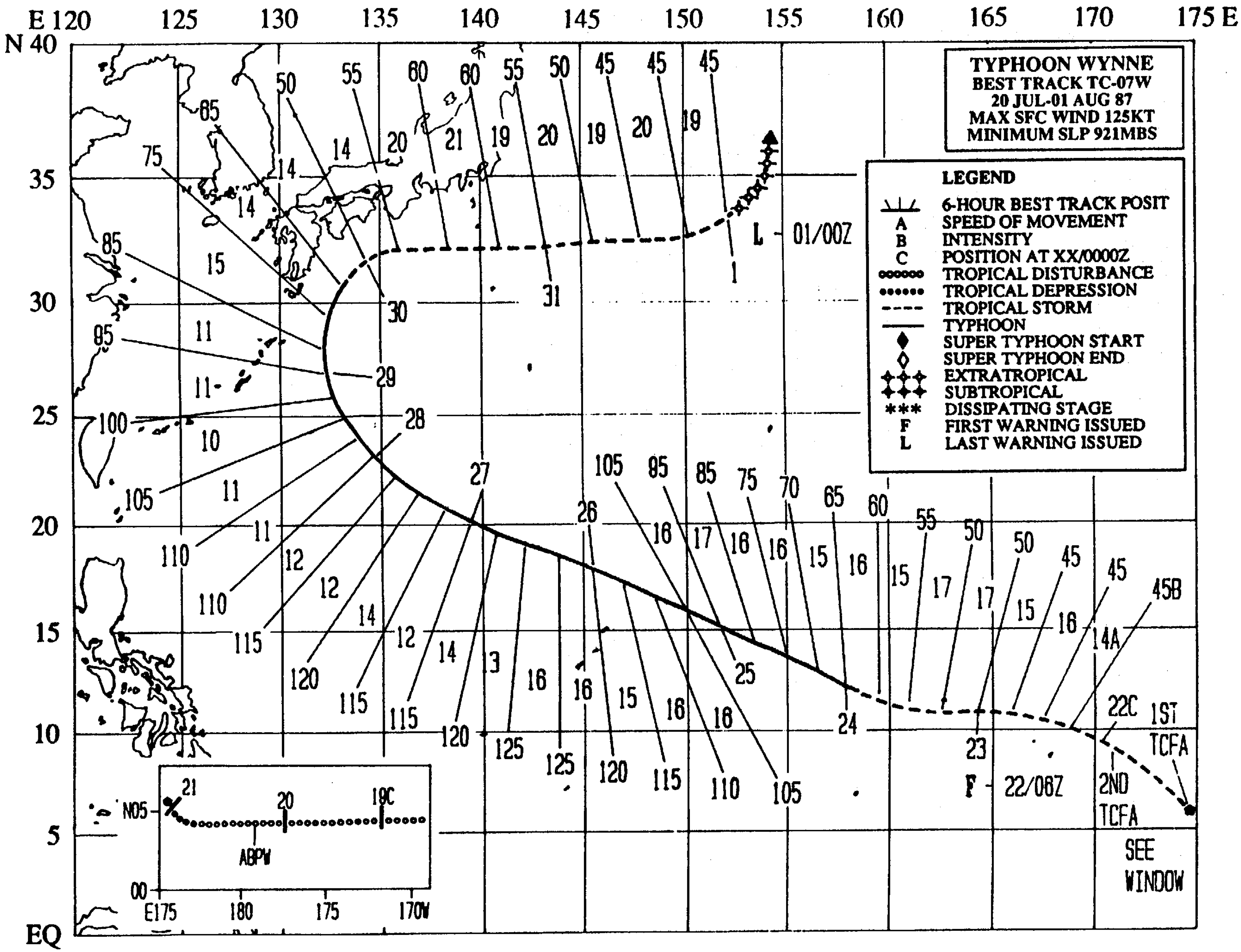


Figure 3-06-6. The spiralling rainband of Vernon as seen by radar from Hualien, Taiwan (WMO 46699) at 201500Z July (Photograph courtesy of Central Weather Bureau, Taipei, Taiwan)..

Vernon began to track steadily northeastward toward Taiwan. It reached minimal typhoon intensity at 191200Z (see Figure 3-06-5). At that point positioning by satellite was no longer a problem due to the better defined central features. On 21 July, Typhoon Vernon began to interact with the terrain of Taiwan as it skirted the eastern shore and rapidly weakened to a tropical depression (Figure 3-06-6). Vernon dissipated in the East China Sea on 22 July after passing the northern tip of Taiwan.



TYPHOON WYNNE
BEST TRACK TC-07W
20 JUL-01 AUG 87
MAX SFC WIND 125KT
MINIMUM SLP 921MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 01/00Z
F - 22/06Z
1ST TCFA
2ND TCFA
SEE WINDOW
ABPW
E 120
175 E
N 40
EQ

TYPHOON WYNNE (07W)

Typhoon Wynne was the fifth typhoon in the western North Pacific in 1987 and was of interest due to several factors. Early communication with meteorologists from Kwajalein Atoll (WMO 91366) proved instrumental in relocating Wynne, using radar fixes during its formative stages. The system developed into the third "midget" typhoon of the year and maintained a visible eye for six days. Wynne tracked along a constant 294 degree bearing for four consecutive days, during which time, it crossed the northern Mariana Islands, causing extensive damage to the islands of Alamagan and Agrihan.

Wynne appeared as an amorphous, but persistent, mass of cloud in the maximum cloud zone east of the dateline and was first mentioned on the 200600Z July Significant Tropical Weather Advisory (ABPW PGTW). Analysis of the sparse synoptic data indicated convergence enhancing cross-equatorial low-level flow into the system in the horizontal with moderate wind shear in the vertical.

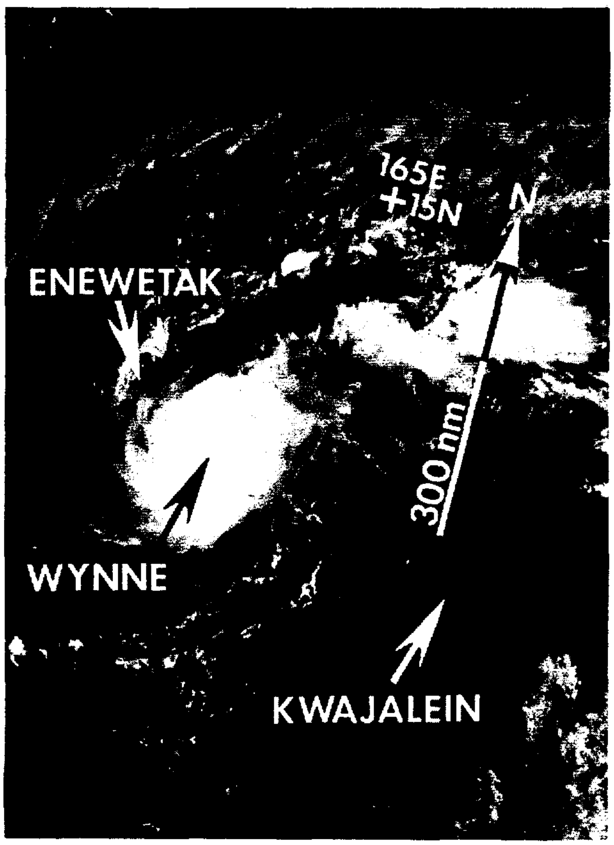


Figure 3-07-1. Wynne at the tropical storm stage of development about 200 nm (370 km) west-northwest of the Kwajalein Atoll. Note the relatively cloud-free ring surrounding the small bright CDO (222300Z July DMSP visual imagery).

Wynne moved westward and continued to improve in convective organization. Satellite intensity analysis (Dvorak, 1984) of the well-defined spiral cloud bands at 210000Z estimated 30 kt (15 m/sec) surface winds and 45 kt (23 m/sec) surface winds were forecast for the next day. Based on this information, a Tropical Cyclone Formation Alert (TCFA) followed at 210430Z. Through the 20th, Wynne's track remained westward in response to the synoptic-scale flow south of the subtropical ridge axis. On 21 July, however, satellite reconnaissance fix positions indicated cloud system center movement towards the northwest. Due to this track change the alert area was redefined at 212030Z and the TCFA was reissued.

Discussions on 22 July between the Typhoon Duty Officer (TDO) and meteorologists on the Kwajalein Atoll, Marshall Islands, provided invaluable positioning information. Kwajalein was receiving light winds and radar showed the main convection associated with the tropical cyclone to be well to the north of their location. The result was a 120 nm (222 km) northward relocation of the 221200Z warning position from its expected location. By the end of the day, Wynne had separated from the maximum cloud zone and drawn down into a small bright central dense overcast (CDO) (Figure 3-07-1).

An eye first became visible on satellite data at 240000Z. From that point onward (a period of six days), the system was characterized by a small eye. The eye diameter changed slightly from 12 nm (22 km) to 18 to 22 nm (33 to 41 km) in diameter. Typical of a smaller than normal system, it had smaller than average 30 kt (15 m/sec) wind radii. Aircraft reconnaissance revealed this anamoly.

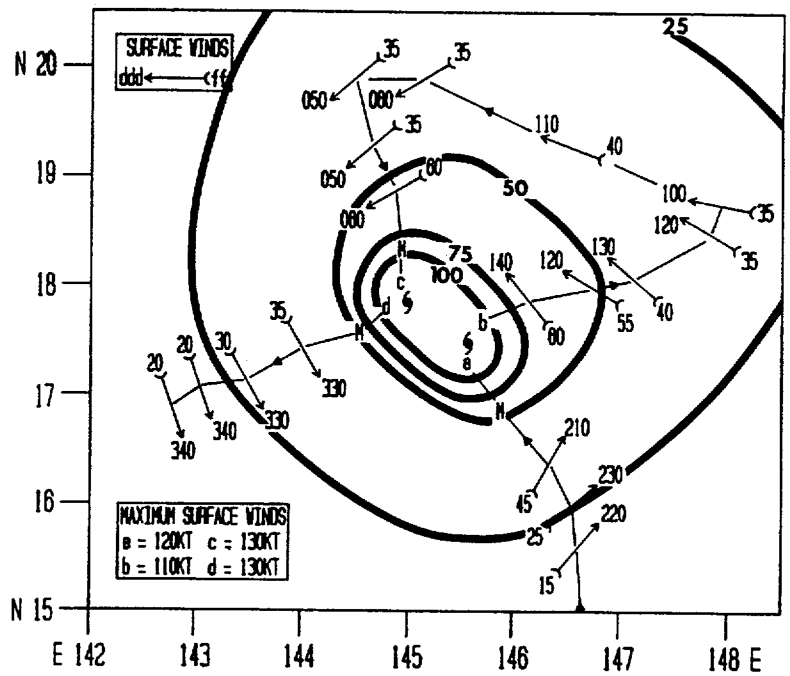


Figure 3-07-2. Plot of aircraft reconnaissance data from 252134Z to 260125Z July, showing the surface and 700 mb flight-level wind distribution around Typhoon Wynne. Note the greater extent of the wind radii in the northeastern semicircle.

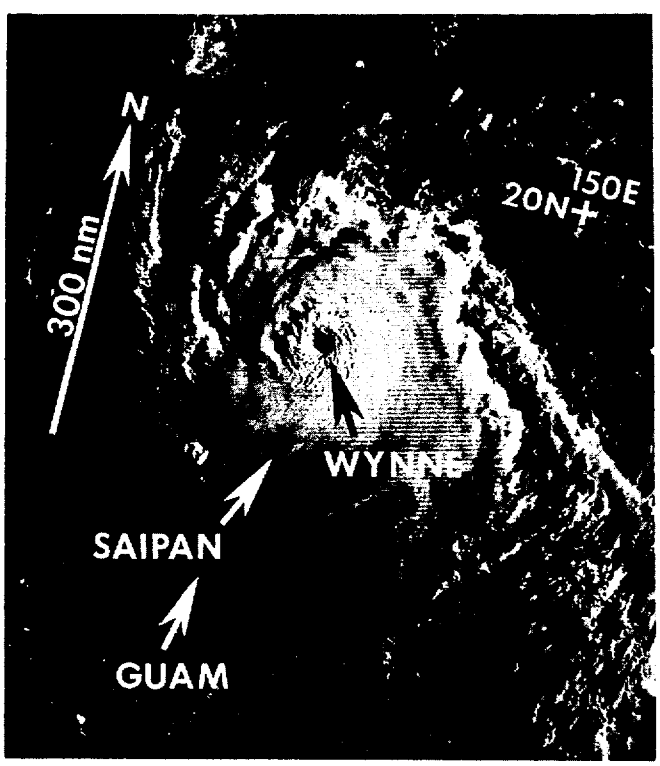


Figure 3-07-3. Typhoon Wynne two hours before crossing the northern Marianas and near its closest point of approach to Guam. With the low morning sun off the right side of the picture, differences in cloud top heights are accentuated by shadowing. In this image an apparent 'stadium' effect can be seen; the larger upper-level inner eye wall boundary slopes downward to the concentric smaller low-level eye (252015Z July DMSP visual imagery).

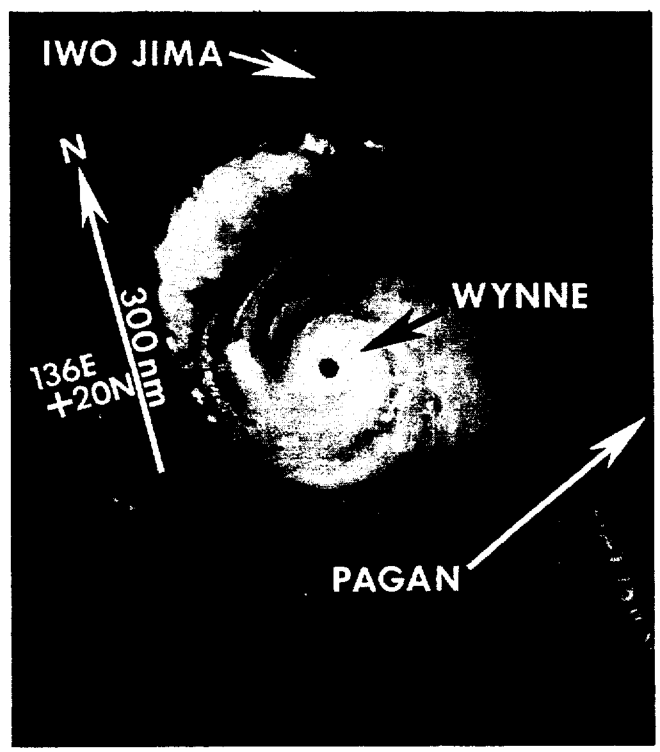


Figure 3-07-4. Midget Typhoon Wynne near maximum intensity. Note the well-defined 15 nm (28 km) eye (261815Z July NOAA infrared imagery).

Wynne's wind radii were nearly twice as large in the northeast semicircle as elsewhere (Figure 3-07-2). This appears to be related to the pressure gradient between Wynne and the subtropical anticyclone to the north. Figure 3-07-3 shows Typhoon Wynne two hours before it passed directly over the northern Marianas island of Alamagan (240 nm (444 km) north-northeast of Guam). At approximately the same time (240000Z through 271200Z) Wynne followed an almost straight track along a mean 294 degree bearing. While on this course and mean speed of 16 kt (30 km/hr), the typhoon attained its maximum intensity of 125 kt (64 m/sec) on the 26th (Figure 3-07-4).

An interesting aspect of Wynne's travel across the western North Pacific was that it maintained a brisk forward speed of movement, even through recurvature, where it slowed only slightly to 10 kt (19 km/hr). Typically, a larger decrease in forward speed is expected as a system passes through the area of weaker steering flow at the break in the subtropical ridge axis.

As Wynne rounded the western end of the mid-level subtropical ridge, it began to experience increasing vertical shear from the north. The exposed low-level cyclonic circulation became visible at 291500Z (Figure 3-07-5). Even with this unfavorable environment in the vertical, there were strong winds associated with the system for the next two days. Aircraft reconnaissance at 291111Z found 700 mb winds of 76 kt (39 m/sec).

Wynne was downgraded from typhoon to tropical storm intensity on the 32nd warning (valid at 300000Z) after a satellite intensity estimate of 50 kt (26 m/sec) was attained. Subsequent aircraft reconnaissance at 292157Z and 300027Z also reported maximum 700 mb flight-level winds of 60 kt (31 m/sec).

Wynne continued slowly weakening as it moved eastward, south and southeast of the main Japanese island of Honshu. Its forward speed increased as a result of stronger mid-level westerly flow. At the same time, Wynne began entraining cooler, drier air from the north. As a consequence, extratropical transition was complete at 010000Z August.

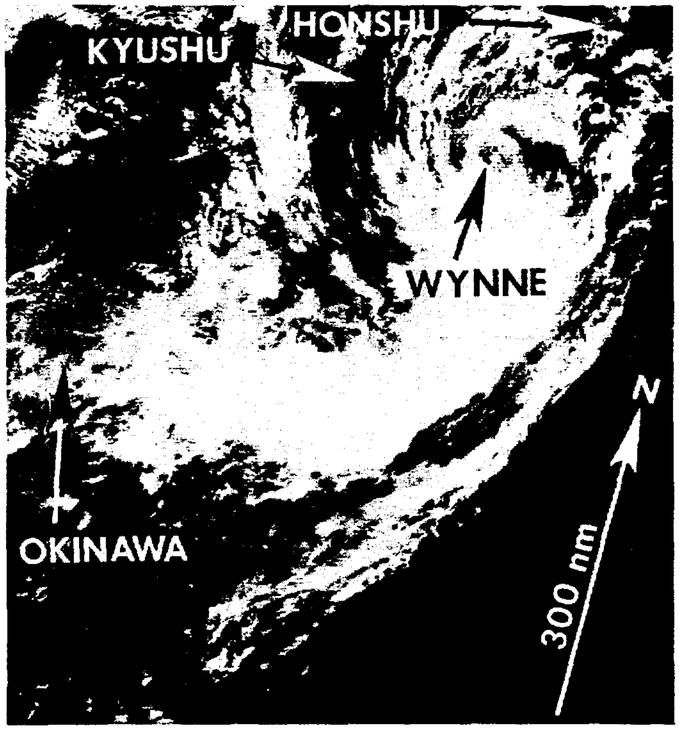
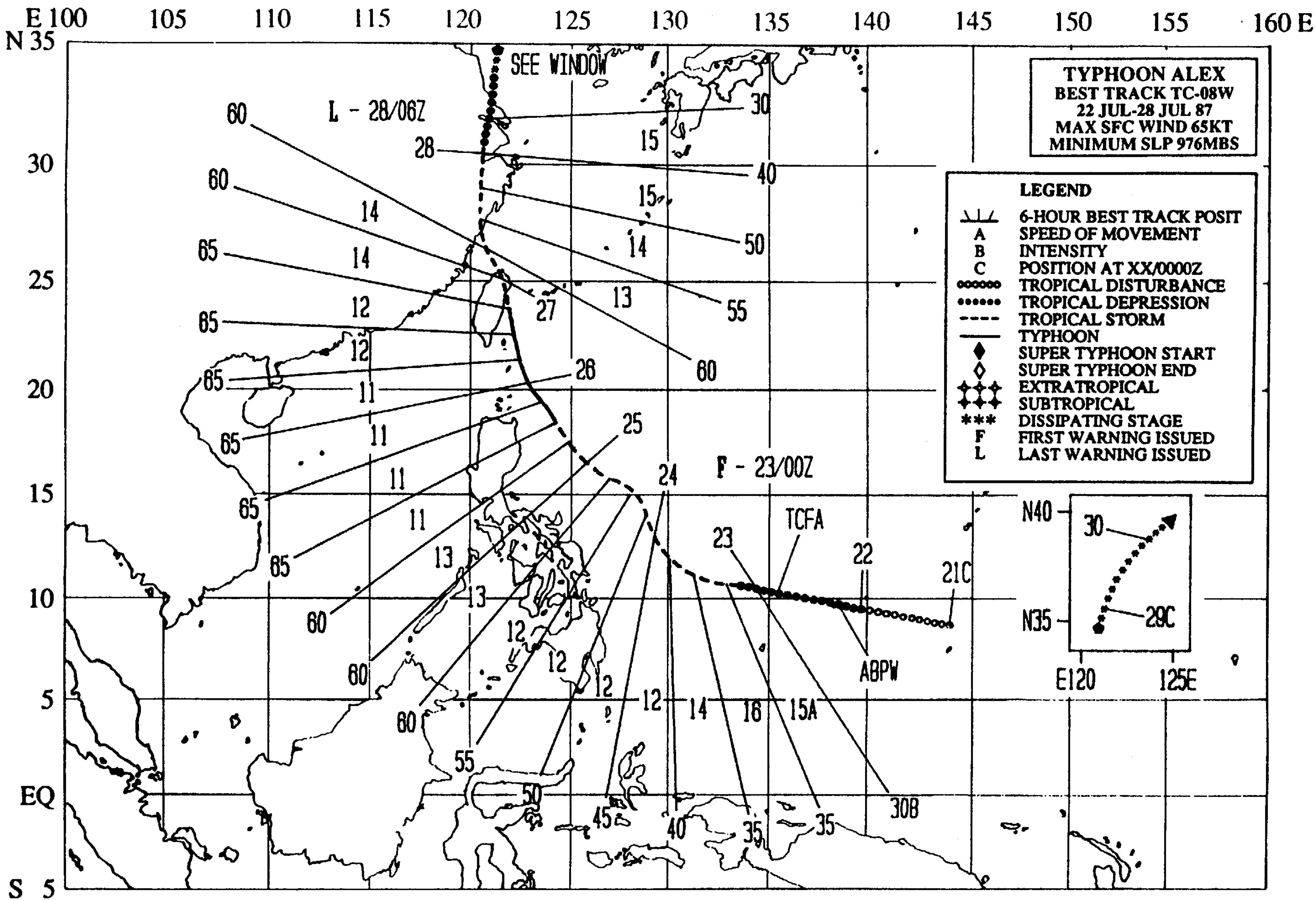


Figure 3-07-5. Wynne, at tropical storm intensity 130 nm (241 km) east of the Japanese island of Kyushu. Low-level cloudiness defines the exposed circulation center. Of interest, the bright and dark patches on the ocean's surface to the east of the system are the result of sun-glint. These patches indicate the areas of relatively smooth ocean surface with less wind waves which are usually the result of lighter surface winds near the axis of the lower-tropospheric subtropical ridge. In this case the ridge axis runs east-to-west near 22 degrees North Latitude. Understanding the location and atmospheric processes associated with this ridge are vitally important to tropical cyclone forecasting (292359Z July DMSP visual imagery).

In retrospect, the islands of Alamagan and Agrihan suffered the only recorded major damage due to Wynne's passage. Their crops were 90 to 100 percent destroyed and all coconut trees were downed. Fortunately no lives were lost. Except for this head-on meeting between Wynne and these islands, no synoptic data revealed the potent punch of this midget typhoon. Only direct aircraft measurement and indirect satellite reconnaissance recorded the wind intensities because of the system's small size.


TYPHOON ALEX
BEST TRACK TC-08W
22 JUL-28 JUL 87
MAX SFC WIND 65KT
MINIMUM SLP 976MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
SEE WINDOW
L - 28/06Z
F - 23/00Z
TCFA
ABPW
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
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25
20
15
10
5
EQ
S 5
N40
N35
E120
125E

TYPHOON ALEX (08W)

Typhoon Alex was the fourth and final tropical cyclone to develop during the month of July, and combined with Typhoon Wynne (07W) to form the first multiple-storm situation of the 1987 western North Pacific tropical cyclone season. Wynne (07W) passed through the Marshall Islands and intensified to tropical storm intensity as Alex showed initial signs of development on July 22nd. Six days later, on the 28th, Wynne (07W) began to slowly recurve south of Japan as Alex dissipated over the eastern China coast. The closest the two systems came to one another was 740 nm (1370 km) late on the 28th.

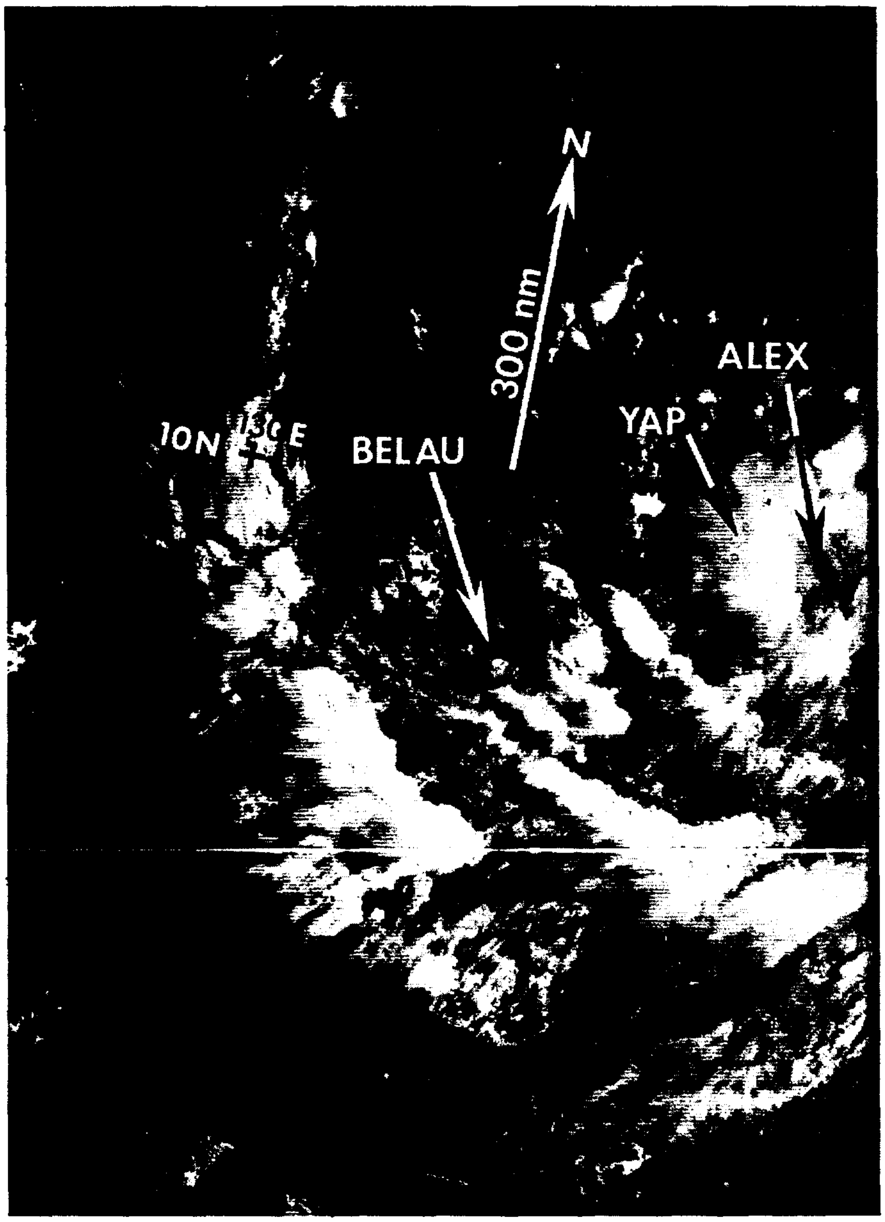


Figure 3-08-1. Morning view of the tropical disturbance in the Philippine Sea which would develop into Typhoon Alex. Convective banding is evident in the low-level cloud lines (220102Z July DMSP visual imagery).

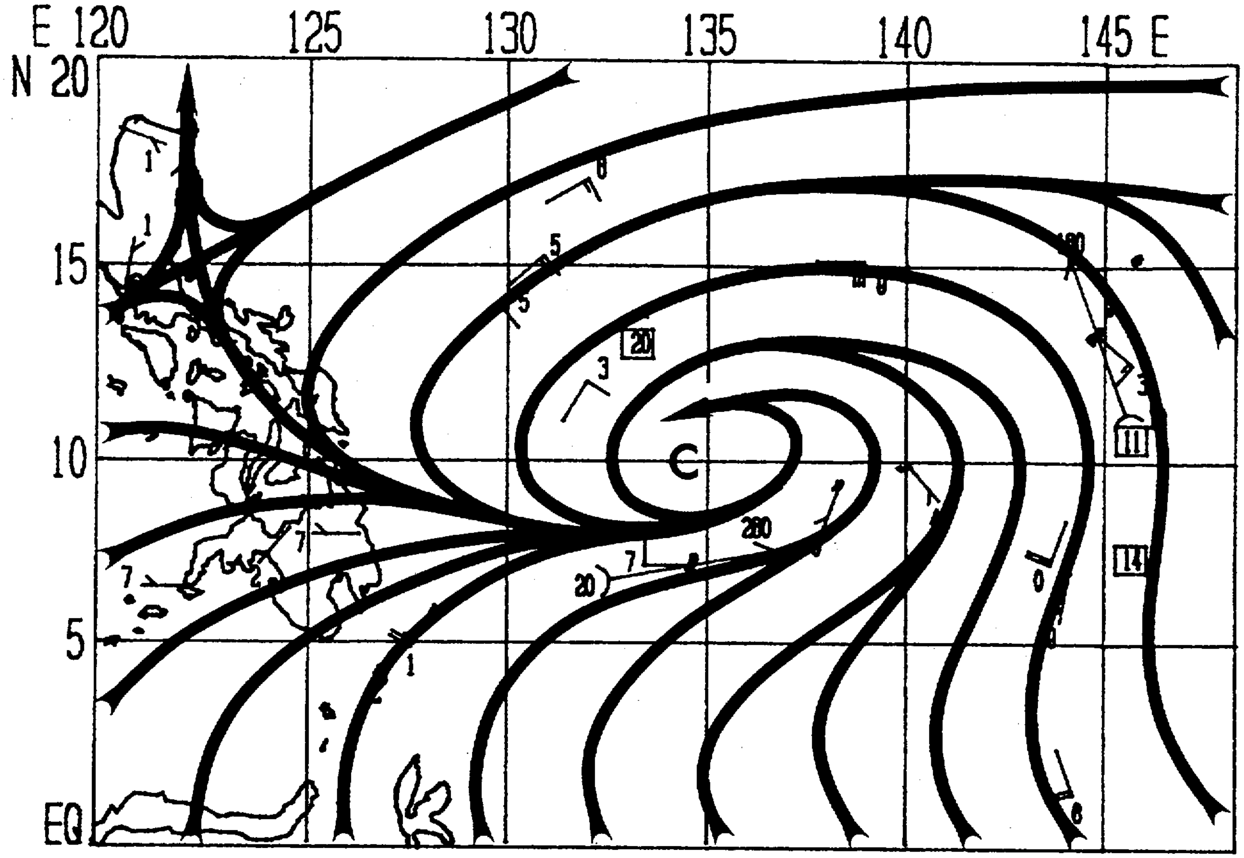


Figure 3-08-2. Synoptic surface/gradient-level streamline analysis of 230000Z July data shows a broad cyclonic circulation in the Philippine Sea with an estimated minimum sea-level pressure of 1000 mb and winds of 30 kt (15 m/sec). (Note: drifting buoy wind speeds (in kt) enclosed in boxes.)

Alex developed in the western end of an active monsoon trough which stretched east-to-west 2400 nm (4445 km) (south of 10 degrees North Latitude) from the dateline across the Marshall and Caroline Islands. Late on the 21st, routine analysis of satellite imagery indicated a tropical disturbance persisting in an area of poorly organized convection 200 nm (370 km) to the southwest of Guam. This area was noted on the Significant Tropical Weather Advisory (ABPW PGTW) at 220600Z due to its persistence and indications of convective banding in the low-level cloud lines visible on visual imagery that morning (Figure 3-08-1).

Over the next twelve hours, the convection increased and upper-level organization improved rapidly. Infrared satellite imagery at 221800Z indicated a central core of heavy convection had developed. Surface winds were estimated at 25 kt (13 m/sec) based on the Enhanced Infrared (EIR) technique (Dvorak, 1984). As a result, JTWC promptly issued a Tropical Cyclone Formation Alert (TCFA) at 221930Z even though synoptic data indicated only a broad surface circulation with an estimated minimum sea-level pressure of 1005 mb.

Satellite intensity analysis at 230000Z estimated surface winds of 35 kt (18 m/sec) associated with this disturbance. A 30 kt (15 m/sec) ship observation north of the disturbance for this same time provided some ground truth to the Dvorak estimate (see Figures 3-08-2 and 3-08-3). Based on these data, JTWC immediately issued the first warning on Tropical Depression 08W. Six hours later, on the second warning, Alex was upgraded to tropical storm intensity based on increased organization that became evident on satellite imagery at 230600Z. Within 12-hours a well-defined convective band could be seen on satellite imagery wrapping into the center.

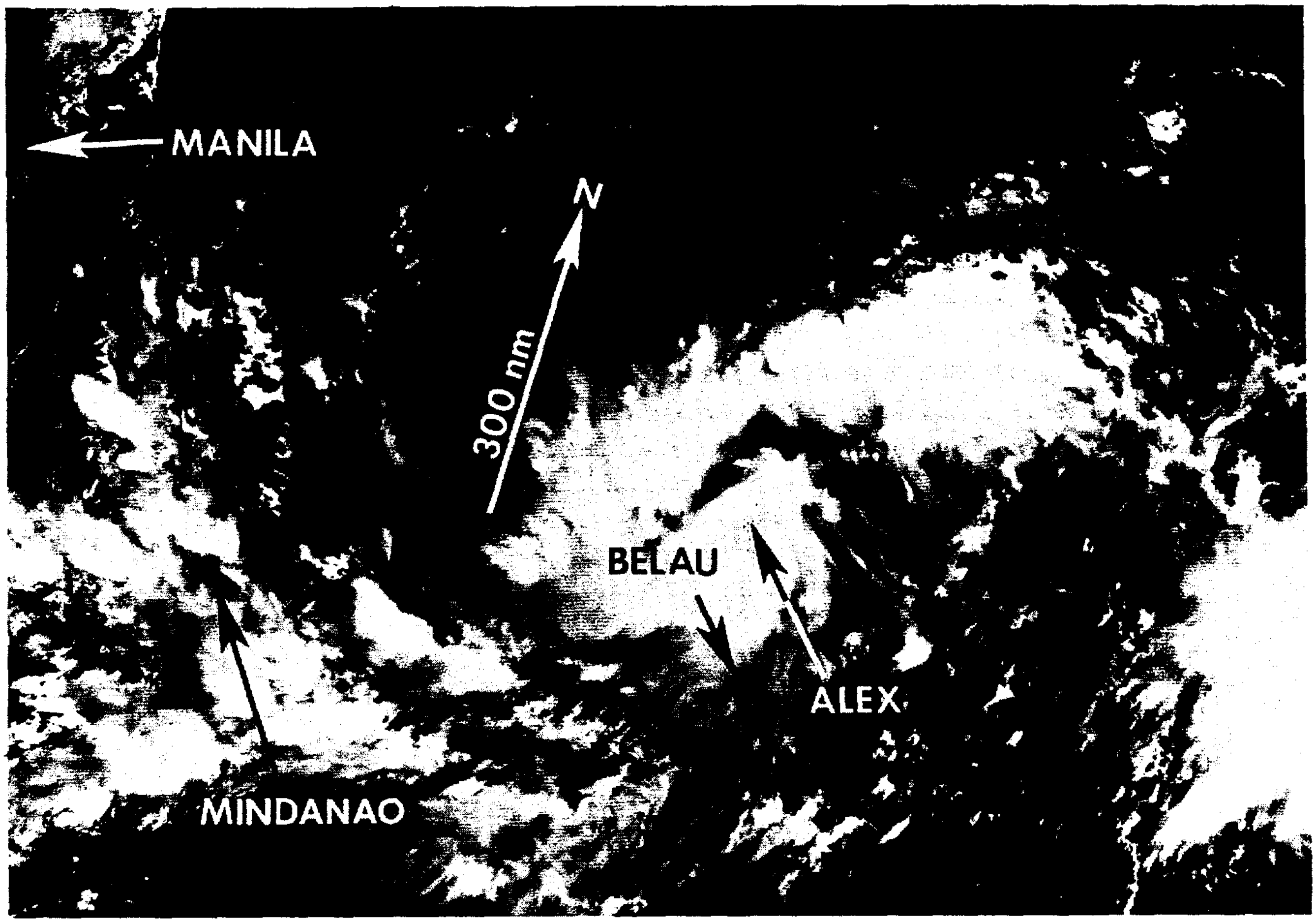


Figure 3-08-3. Visual satellite imagery near the time of the first warning on Tropical Depression 08W. See the 230000Z July synoptic surface/gradient-level streamline analysis in Figure 3-08-2 for comparison (230041Z July DMSP visual imagery).

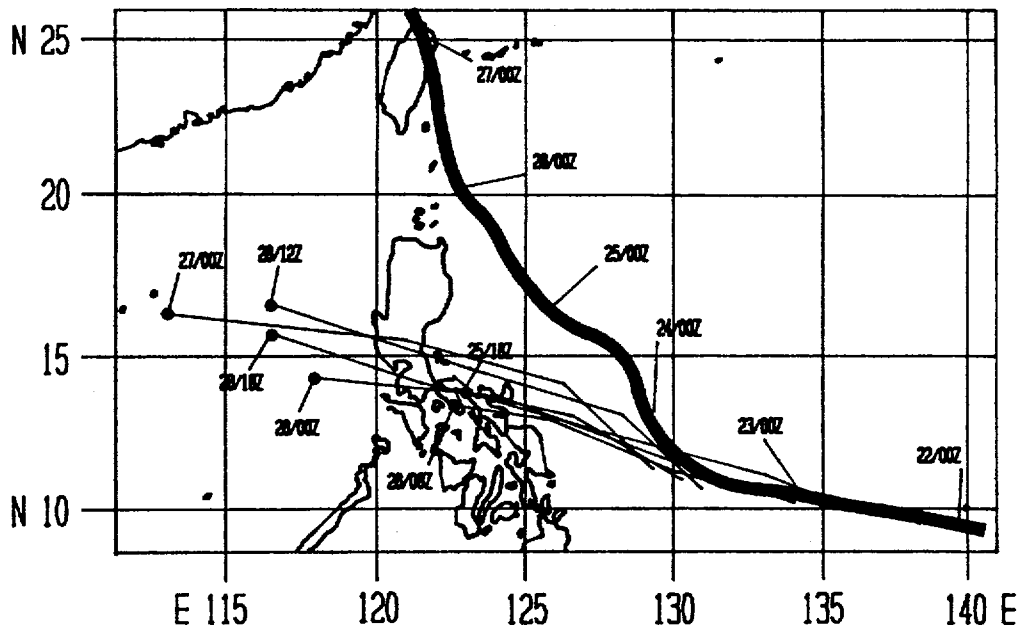


Figure 3-08-4. Initial OTCM 72-hour guidance for Alex indicated the system would remain south of the subtropical ridge and move across the Philippine Islands. Alex's best track is also shown for comparison.

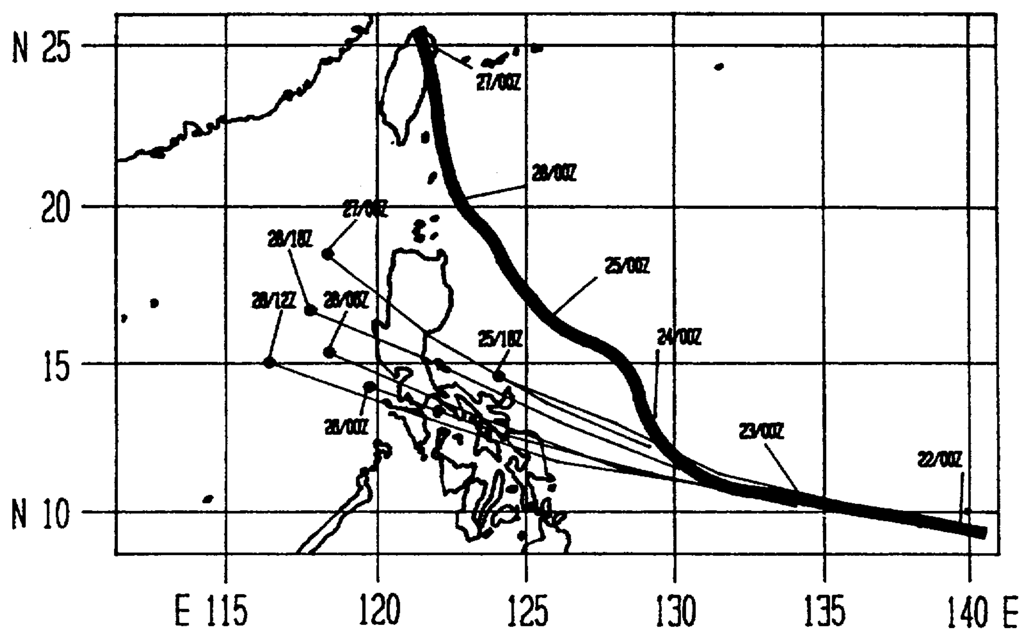


Figure 3-08-5. Initial HPAC 72-hour guidance for Alex agreed with the OTCM in keeping the system south of the subtropical ridge and moving it across the Philippine Islands. Alex's best track is also shown for comparison.

The main forecast problem occurred early, during the first two days of the system's lifetime. Alex was forecast to track across the Philippine Islands on warnings one through five. The primary guidance came from two forecast aids -- the One-Way Interactive Tropical Cyclone Model (OTCM) and the Half Climatology and Persistence Model (HPAC). Figures 3-08-4 and 3-08-5 show the guidance received for the first six warnings from the OTCM and HPAC, respectively. They incorrectly suggested Alex would remain south of the strong subtropical ridge, move across the Philippine Islands and then turn northward towards mainland China. JTWC forecasters determined the OTCM and HPAC guidance was flawed and, on the sixth warning, relocated Alex further north after several satellite fixes indicated it was moving towards the northwest rather than the west-northwest. Unfortunately, beginning at 240900Z, there was increased scatter in the satellite fixes as a cirrus canopy developed over the center. This left JTWC forecasters with no clear-cut indication of exactly where Alex's low-level center was. A solitary aircraft radar fix was obtained at 240916Z which provided some close in information, however a trained Aerial Weather Reconnaissance Officer was not onboard the flight and the meteorological accuracy of the position was suspect. Figure 3-08-6 shows a satellite image prior to the time of the aircraft fix. Notice the exposed low-level center is displaced slightly northeast of the heaviest convection. The radar site at Guiuan (WMO 98558) in the Philippine Islands fixed this area of heavy convection and added to the uncertainty as to where the actual location of Alex's center was.

Forecast guidance for the next five warnings indicated Alex should track through

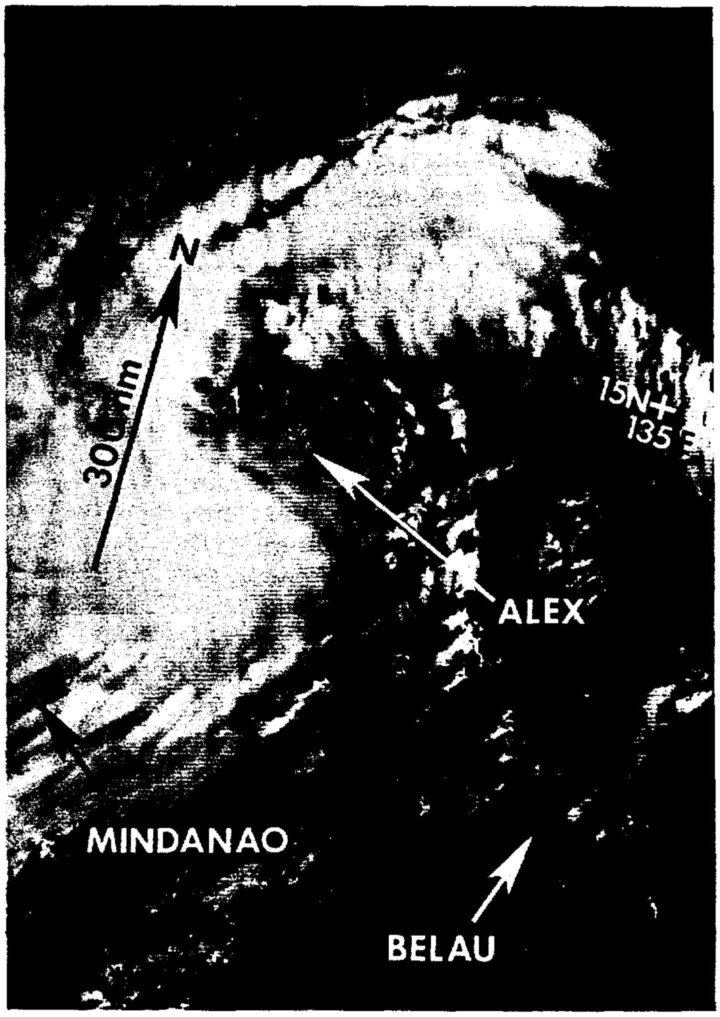


Figure 3-08-6. Morning view of Alex. The exposed low-level center is displaced slightly northeast of the heaviest convection (240021Z July NOAA visual imagery).

the Luzon Strait and make landfall over mainland China to the west of Taiwan. JTWC forecasts for this time period (240600Z through 250600Z) reflected this guidance. Also during this period, Alex continued to slowly intensify. Between 241500Z and 241800Z, it developed an eye. This eye was first implied by a warm spot in the central cloud mass on the nighttime infrared imagery (see Figure 3-08-7).

At 1200Z on the 25th, Alex reached its maximum intensity of 65 kt (33 m/sec) and was upgraded to typhoon status. At that time, Alex was 120 nm (222 km) east of the northeast tip of Luzon. Forecast guidance at 251200Z changed significantly, suggesting a more northward movement, which would take Alex east of Taiwan vice through the Luzon Strait. The reason for this change in computer forecast guidance appears to be twofold. First, a surface frontal boundary stalled across the eastern coast of Asia, and second, a large break developed between the upper-level subtropical ridge south of Japan and the Siberian High.

Alex remained at minimal typhoon intensity for another 30-hours and then began to slowly weaken. It was then steered toward the north by the low-level southerly flow east of the stalled front, which caused it to brush the eastern portion of Taiwan (Figure 3-08-8) and pass within 30 nm (56 km) of the capital city of Taipei.

Shortly after passing Taipei, Alex was drawn slightly westward by the lee effect of its interaction with Taiwan's mountainous terrain. This caused Alex to make landfall on the China coast near the city of Wenzhou, 200 nm (370 km) south of Shanghai. The system then moved inland and dissipated as a significant tropical cyclone. Figure 3-08-9 shows Alex with respect to Wynne for this same time period. Near 281800Z, the remnants of Alex, with its residual vorticity and moisture, once again moved over water but did not regenerate into a significant tropical cyclone. It did, however, add to the band of precipitation that had stalled over Korea and, as a consequence, over 12 inches (300 mm) of rain fell within 24-hours. This deluge triggered major flooding, landslides and loss of life. In contrast, the damage to Taiwan and China was minor.

Figure 3-08-7. An implied eye appears as a warm (white) spot in the central cloud mass (dark gray) (241837Z July NOAA enhanced infrared imagery).

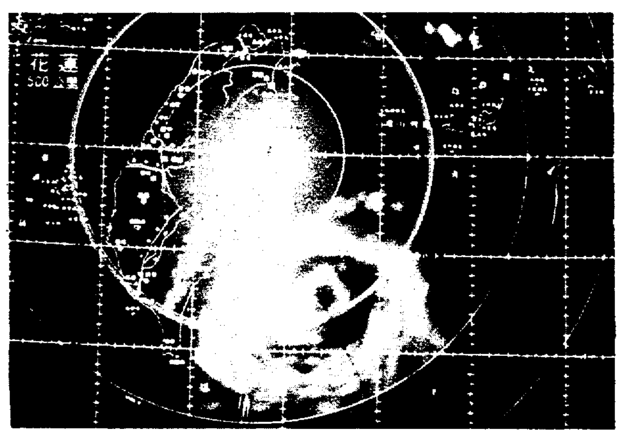


Figure 3-08-8. The tightly curved rainband and eye wall of Typhoon Alex as seen by radar from Hualien, Taiwan (WMO 46699) at 261400Z July (Photograph courtesy of Central Weather Bureau, Taipei,

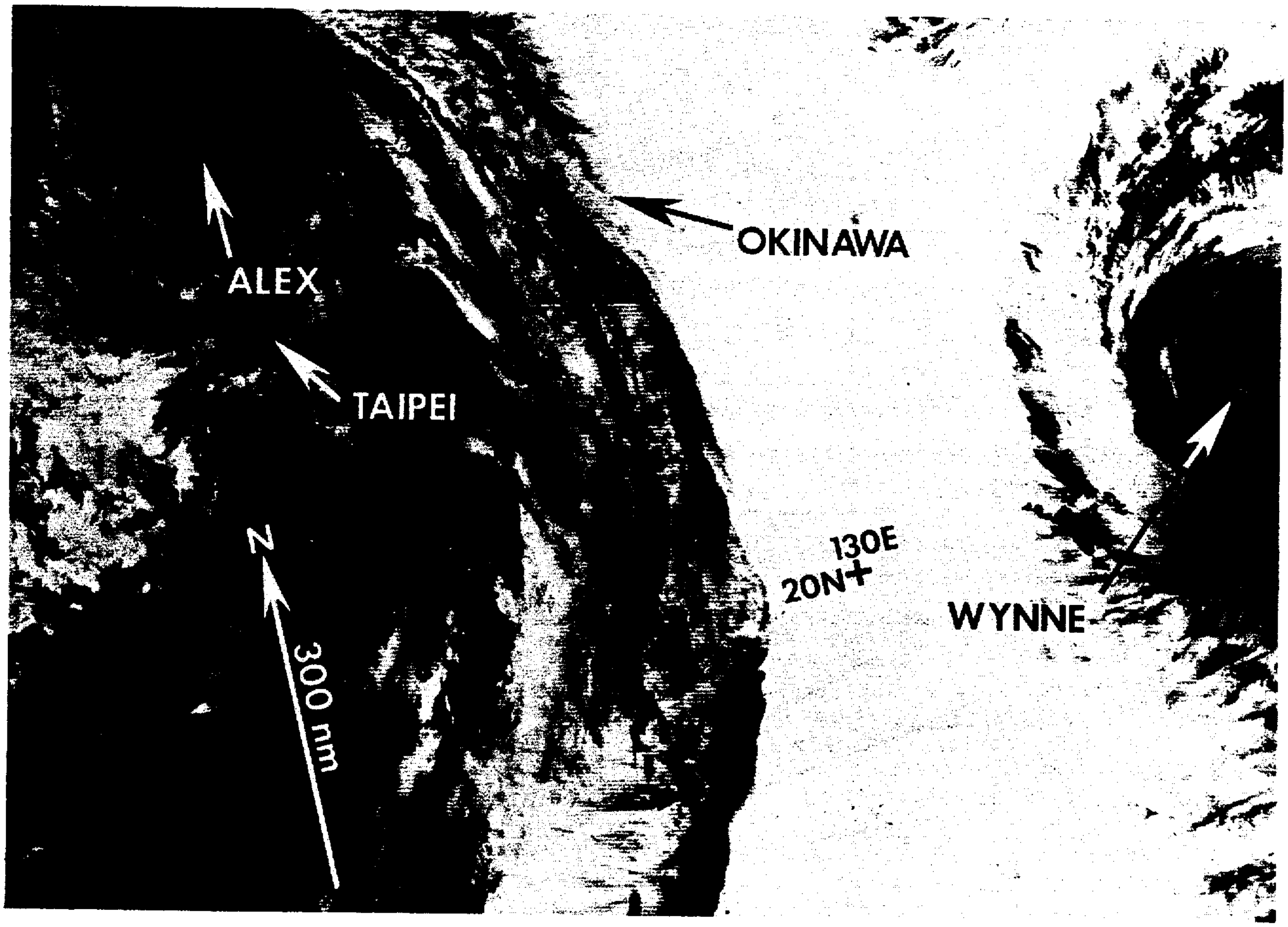
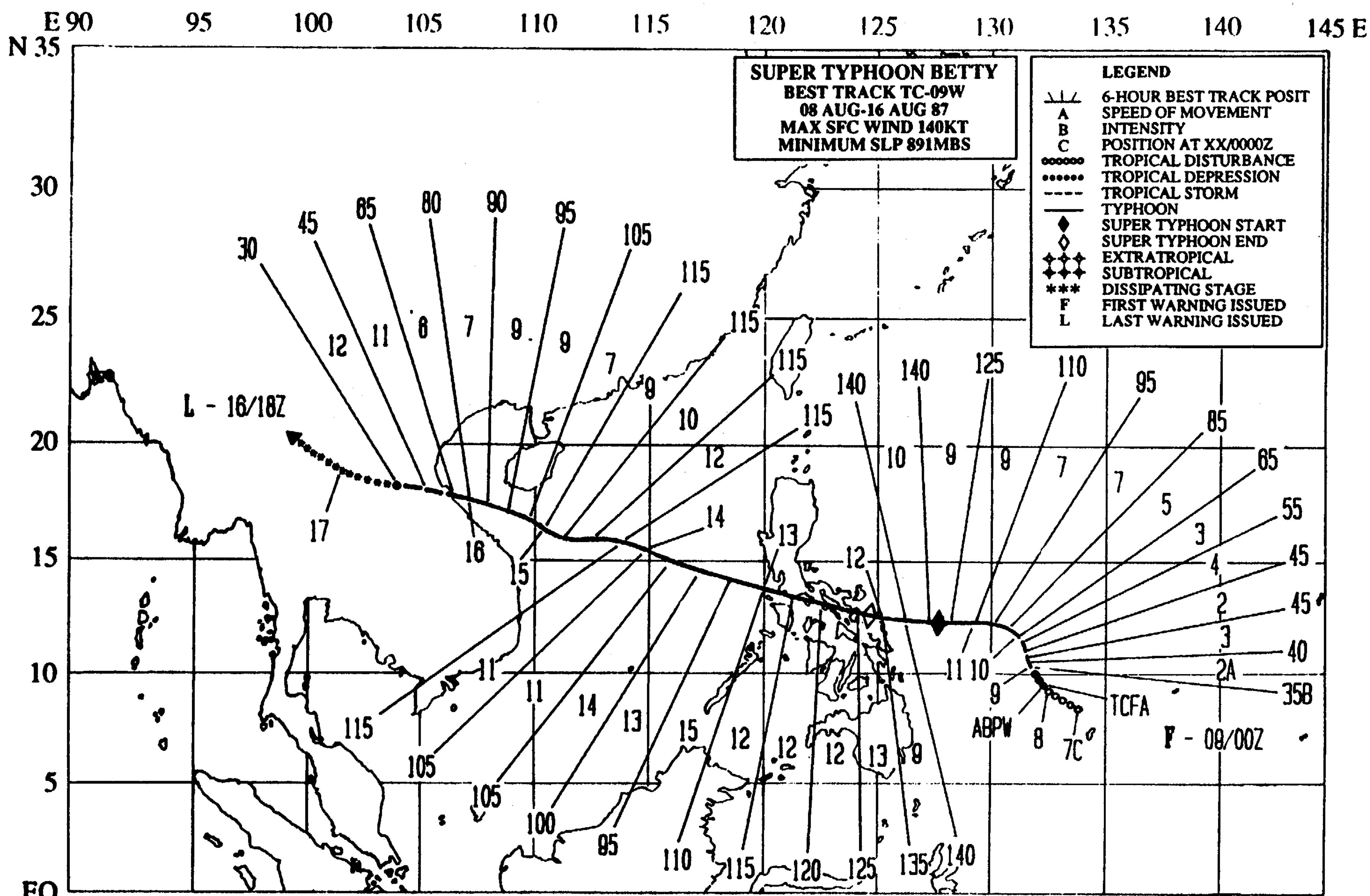


Figure 3-08-9. Typhoons Alex and Wynne (07W) appeared together on this thresholded infrared satellite image (Note: coldest cloud tops appear black). Alex had just moved inland over the eastern coast of China and Wynne was still on a northwestward track, heading toward Okinawa, Japan (271341Z July DMSP inverted infrared imagery).


SUPER TYPHOON BETTY
BEST TRACK TC-09W
08 AUG-16 AUG 87
MAX SFC WIND 140KT
MINIMUM SLP 891MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 16/18Z
F - 08/00Z
TCFA
ABPW

SUPER TYPHOON BETTY (09W)

Super Typhoon Betty was the first of two tropical cyclones to hit Vietnam during the month of August. Betty was also the second super typhoon (intensity equal to or greater than 130 kt (67 m/sec)) of the 1987 western North Pacific tropical cyclone season and had the lowest reported minimum sea-level pressure (891 mb). It intensified (deepened) explosively (Holliday and Thompson, 1979) prior to making landfall in the Philippine Islands. Other distinguishing characteristics were the large size of the area of intense convection, the small radius of maximum wind and the associated strong low-level southwest monsoonal inflow. Also of note was the large radius of gale force winds in Betty's northwest semicircle, due to the enhancement of surface winds by a strong pressure gradient between the tropical cyclone and the subtropical ridge.

After Typhoon Alex (08W), which had developed in the low-level southwest monsoon trough, dissipated on the 28th of July, the mid-level subtropical ridge again became well-established over the western North Pacific. Coincident with Alex's (08W) movement toward the north was the replacement of the strong low-level southwest monsoonal flow over the South China Sea by the ridge.

Betty was first detected on the 7th of August as a tropical disturbance embedded in the monsoon trough, which extended from the Marshall Islands westward to the Philippine Islands. Satellite intensity estimates (Dvorak, 1984) showed surface winds of 25 kt (13 m/sec) when the disturbance was 65 nm (120 km) north-northwest of the island of Belau in the western Caroline Islands. The system cloudiness developed rapidly early on the 8th prompting JTWC to issue a Tropical Cyclone Formation Alert at 0300Z. Figure 3-09-1 shows the disturbance on the 8th of August exhibiting

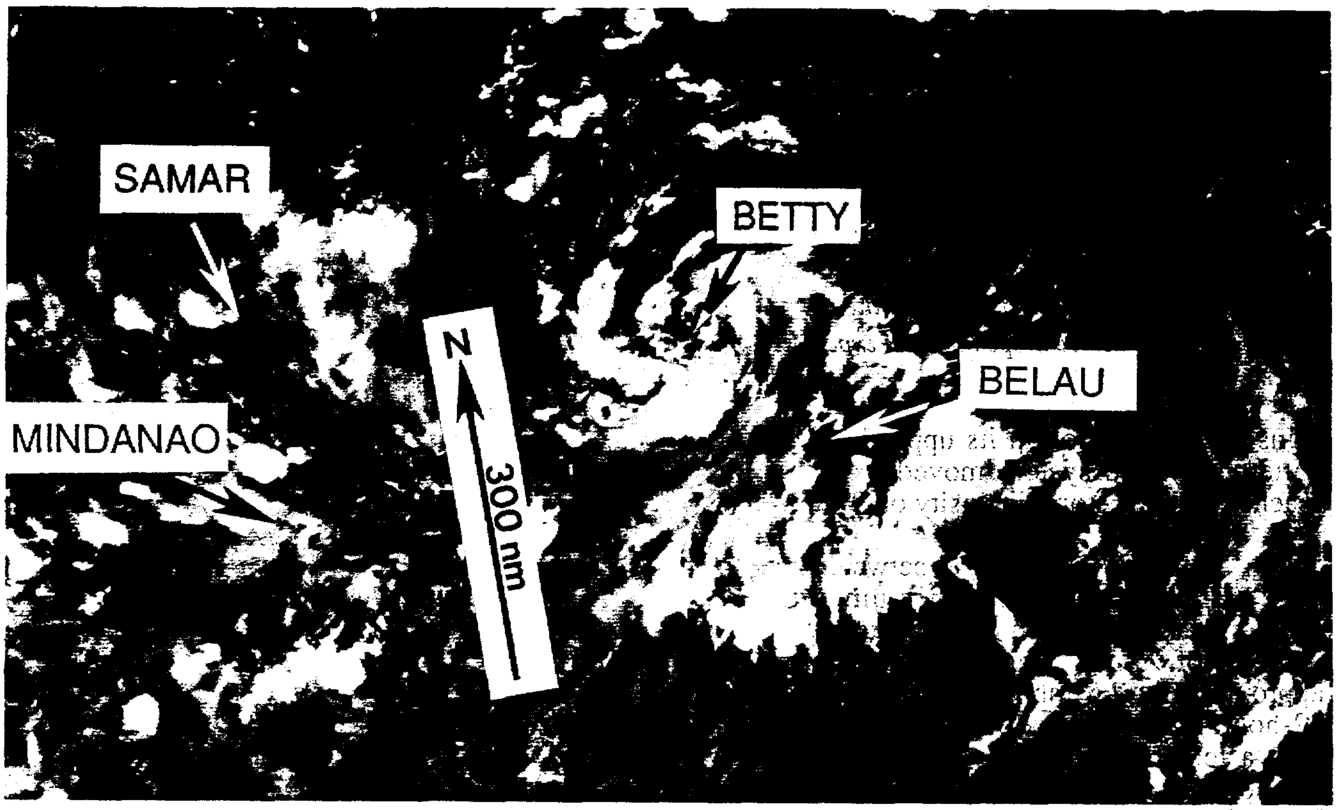


Figure 3-09-1. Super Typhoon Betty as a tropical disturbance in the monsoon trough. Signs of organized upper-level outflow were present (081257Z August DMSP visual imagery).

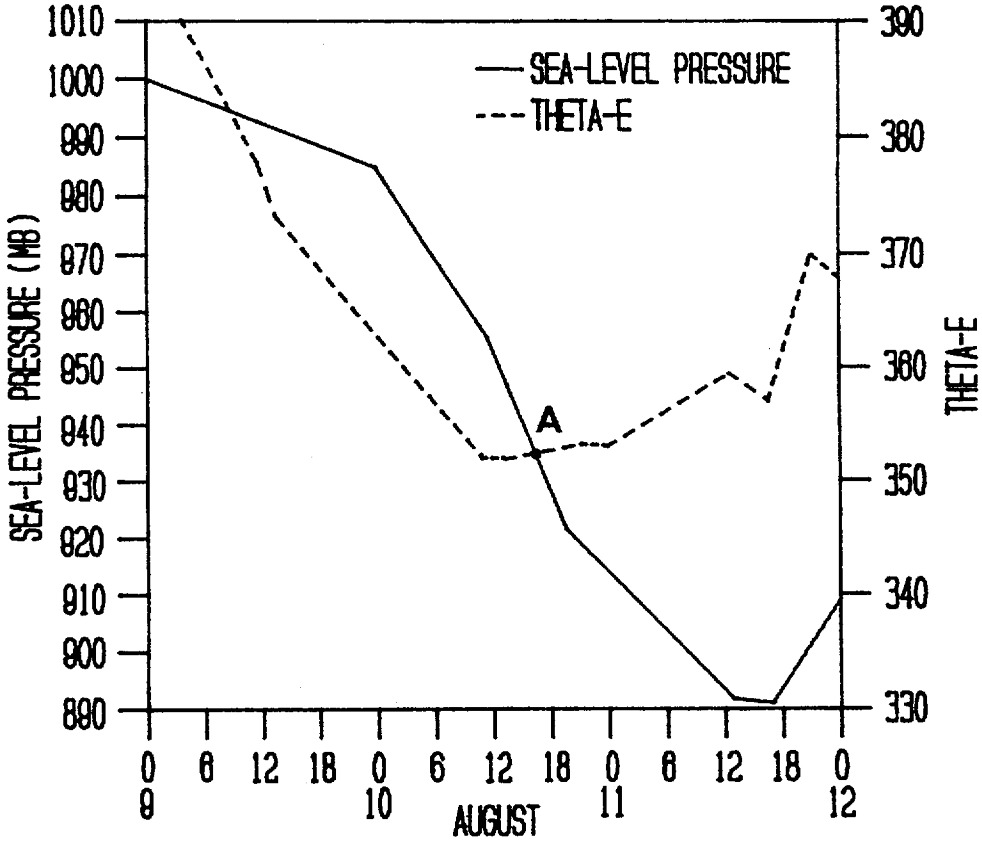


Figure 3-09-2. Plot of Betty's minimum sea-level pressure and central 700 mb equivalent potential temperature during the period 082300Z and 120000Z August. Once the critical crossing of the surface pressure and Theta-E traces occurred (at point A), explosive deepening was expected.

signs of organization in its upper-level outflow pattern. The system moved westward and reached tropical storm intensity on 9 August.

In the 37-hour period between 100000Z and 111300Z, Betty's minimum sea-level pressure dropped from 985 mb to 892 mb, a decrease of 93 mb. This translates to a drop of approximately 2.5 mb/hr (sustained for at least 12-hours) or explosive intensification. JTWC uses a technique (Dunnavan, 1981), in which the 700 mb equivalent potential temperature, Theta-E, (a measure of the tropical cyclone's thermodynamic energy based on the central 700 mb temperature and dew point) and the minimum sea-level pressure are compared to forecast explosive intensification. This technique forecasts intensification to below 925 mb whenever the plots of minimum sea-level pressure and Theta-E intersect near the critical values of 950 mb and 360 degrees Kelvin, both values being statistical means derived from analysis of past intense tropical cyclones. Figure 3-09-2 is a plot of Betty's minimum sea-level pressure and Theta-E during the period 082300Z to 120000Z. At point A (101730Z) the two lines intersect, as the minimum sea-level pressure at this time is plummeting downward. Based on this information, explosive deepening was forecast.

Figure 3-09-3 shows Super Typhoon Betty near maximum intensity with a well-defined eye and intense convection covering a large area around the system. Aircraft reconnaissance on the 10th and 11th of August consistently located the maximum surface winds 10 to 15 nm (19 to 28 km) from the center and radar eye diameters of 11 to 15 nm (20 to 28 km). Both measurements showed the center to be very small and compact.

The threat posed by Super Typhoon Betty resulted in the evacuation of aircraft from Cubi Point Naval Air Station and Clark Air Base, as well as the movement of several ships from Subic Bay. Later, news services reported at least twenty people were killed, seven missing and more than 60,000 left homeless as a result of Betty's passage over the Philippine Islands. Damage to buildings and crops was estimated in the millions of dollars.

Betty weakened from 140 kt (72 m/sec) to 110 kt (57 m/sec) as it accelerated across the central Philippine Islands. The subtropical ridge continued to be the dominant synoptic-scale feature, extending westward into the South China Sea.

After entering the South China Sea early on the 13th of August and still maintaining 95 kt (49 m/sec) winds, Super Typhoon Betty began to reintensify over water as it continued on a west-northwesterly track. By 140600Z, Betty's intensity had peaked again, at 115 kt (59 m/sec), 390 nm (722 km) south of Hong Kong. Betty slowly weakened as it began to interact with the mountains of Vietnam and the island of Hainan which prevented further intensification by hampering its low-level inflow. Crossing the Gulf of Tonkin in less than a day, Betty slammed into the coast of Vietnam 190 nm (352 km) south of Hanoi. The final warning on Betty was issued at 161800Z as the system weakened and dissipated over the mountains inland.

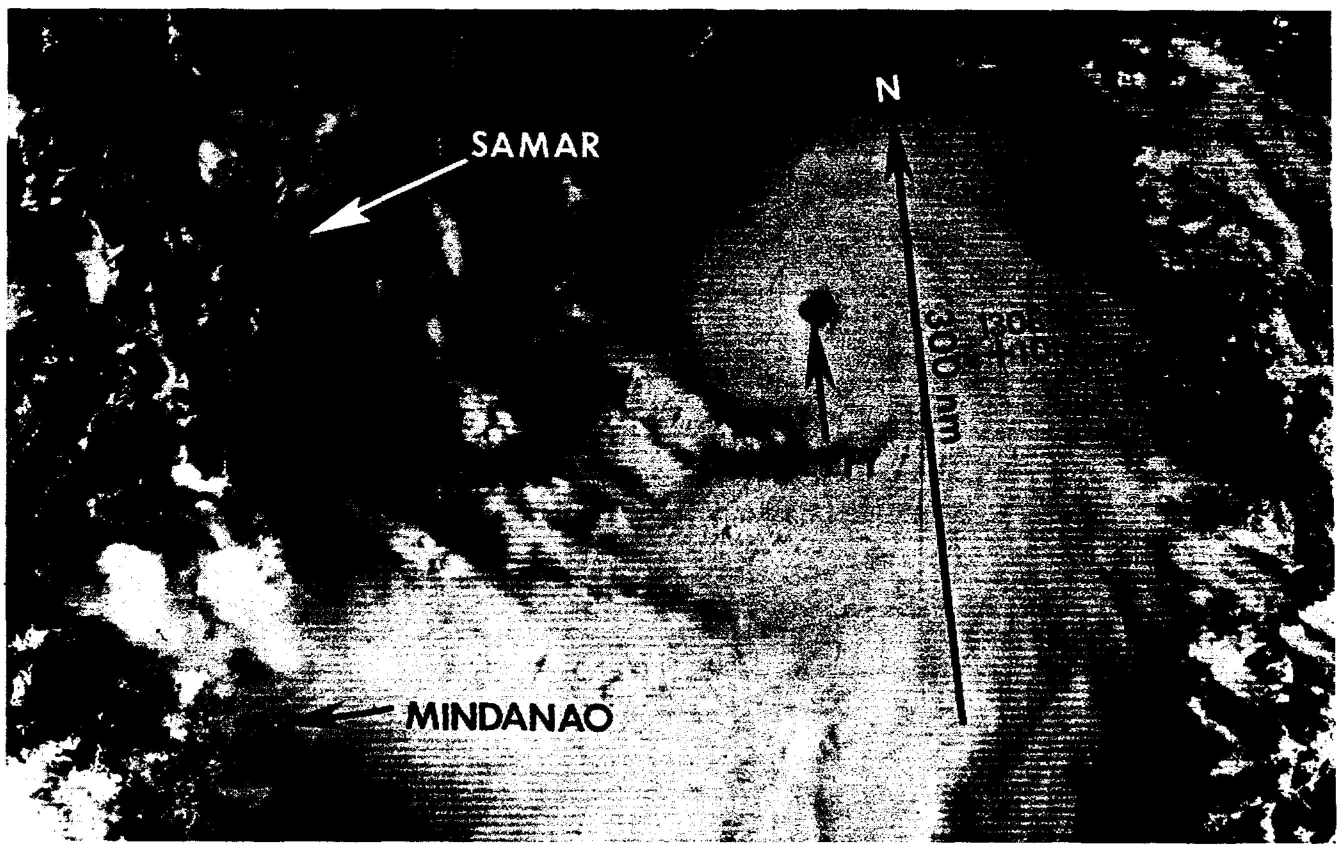
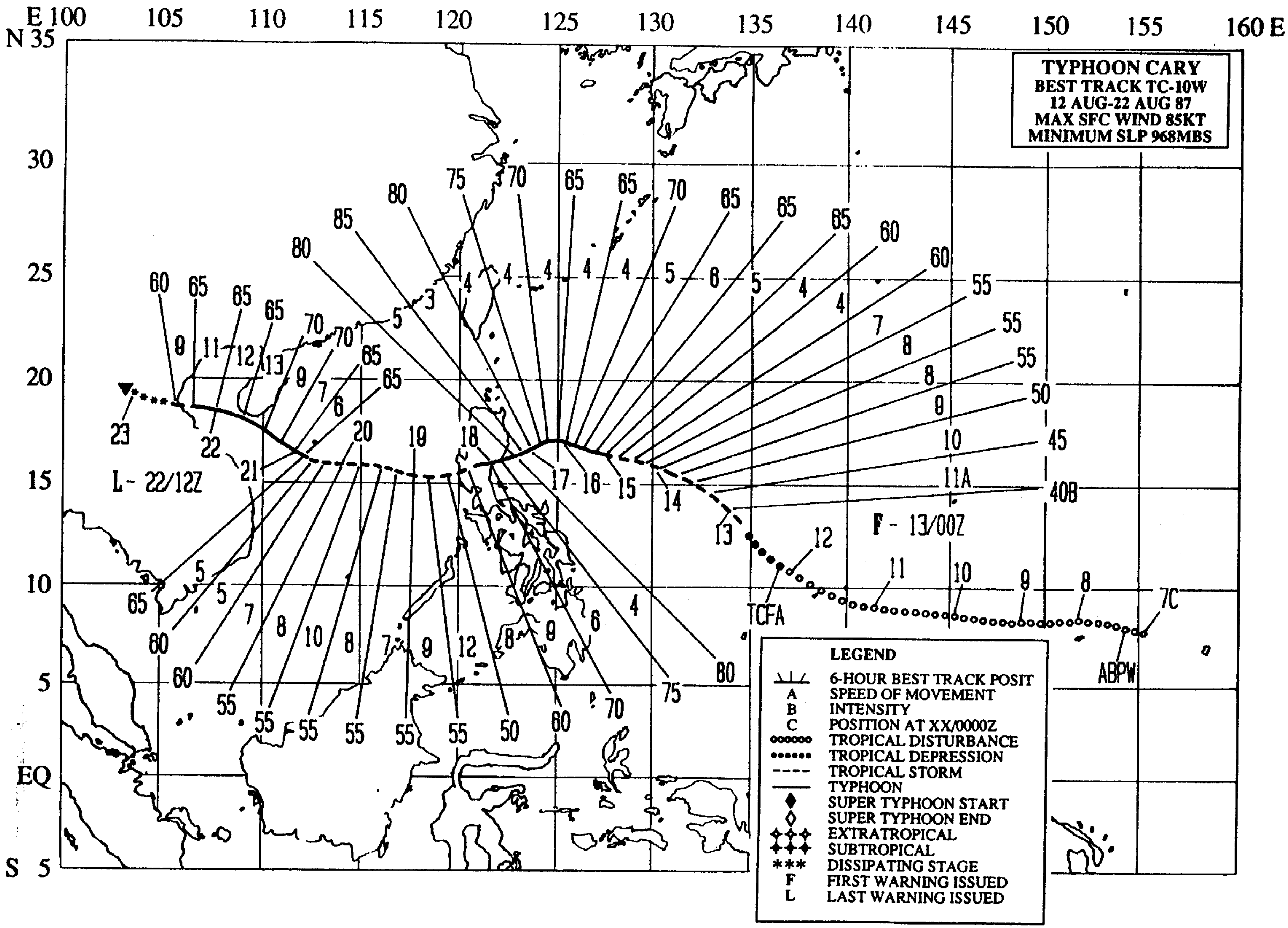


Figure 3-09-3. Super Typhoon Betty near maximum intensity. This expanded image shows the well-defined eye and large symmetrical area of intense convection (110057Z August DMSP visual imagery).



TYPHOON CARY
BEST TRACK TC-10W
12 AUG-22 AUG 87
MAX SFC WIND 85KT
MINIMUM SLP 968MBS
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
S 5
L - 22/12Z
F - 13/00Z
TCFA
ABPW
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON CARY (10W)

Typhoon Cary was the second significant tropical cyclone to develop in August. It shared the western North Pacific with Super Typhoon Betty (09W) for four days; coexisted with Super Typhoon Dinah (11W) for one and a half days, and then was part of the first three-storm situation of 1987 for 12-hours with Dinah (11W) and Tropical Storm Ed (12W).

Cary was first identified on the 6th of August as an area of convection, that persisted longer than usual in the monsoon trough 200 nm (370 km) to the southwest of the island of Pohnpei in the eastern Caroline Islands. As a result, the cloud system was placed on the Significant Tropical Weather Advisory (ABPW PGTW) at 070600Z. The system remained broad and poorly organized over the next four days. By the 12th, upper-level outflow had improved and was unrestricted in all quadrants. Additionally, satellite intensity analysis (Dvorak, 1984) showed winds of 25 kt (13 m/sec). A Tropical Cyclone Formation Alert (TCFA) followed at 120300Z.

Aircraft reconnaissance at 122302Z estimated the maximum surface winds at 55 kt

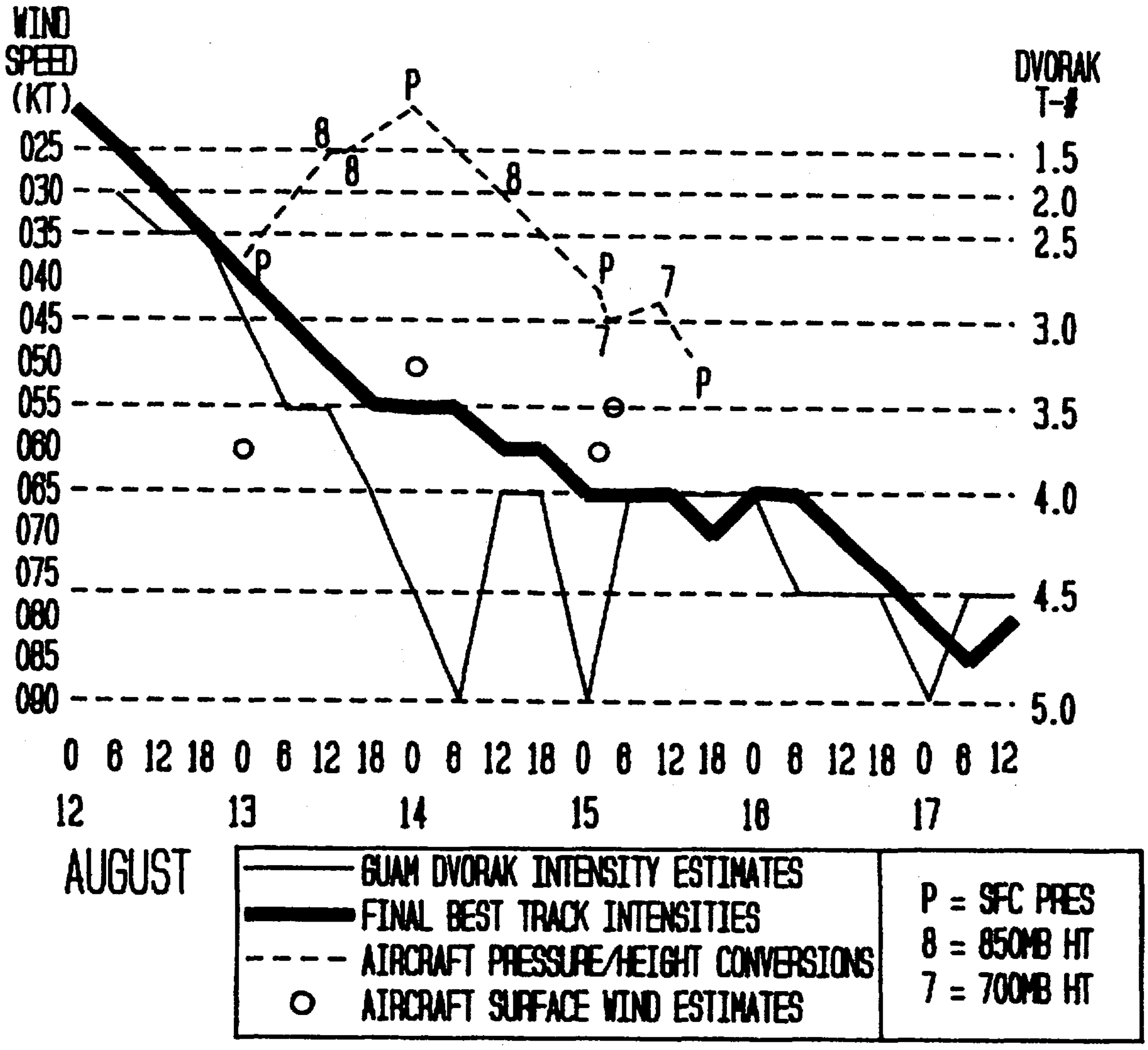


Figure 3-10-1. Time series from 120000Z to 171200Z October showing the natural scatter of raw intensity data and the resulting final best track intensities.

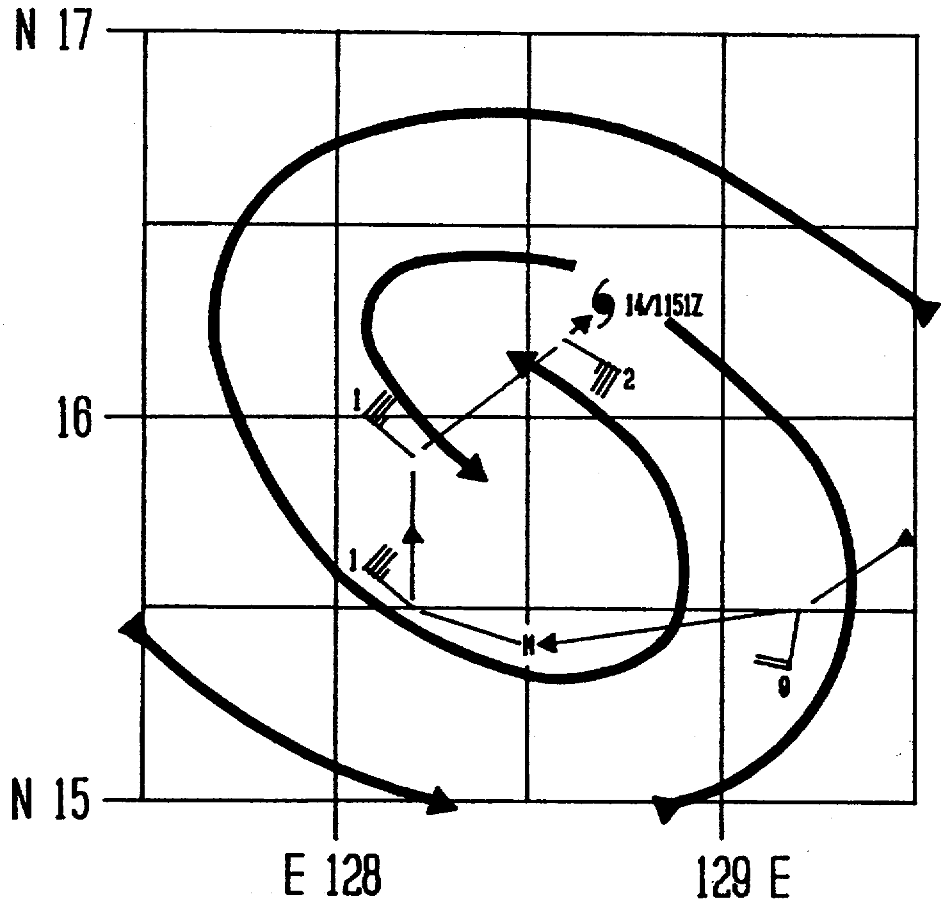


Figure 3-10-2. Plot of data from an aircraft reconnaissance mission at 141151Z August, indicating that the circulation center at flight level (850 mb) was about 18 nm (33 km) to the south of the aircraft fix position.

(25 m/sec), but the minimum surface pressure reported was only 996 mb, which usually supports a maximum wind speed of 37 kt (19 m/sec). At 121800Z, satellite intensity analysis determined that Cary's intensity was 35 kt (17 m/sec). Subsequent satellite intensity analysis, six hours later, indicated that Cary had winds of 45 kt (23 m/sec). Based on these intensity estimates the first warning on Tropical Storm Cary was issued at 130000Z with winds of 50 kt (26 m/sec) gusting to 65 kt (33 m/sec). Post-analysis revealed that Cary most probably had an intensity of 40 kt (21 m/sec) at the time of the first warning, and had reached tropical storm intensity six hours earlier at 121800Z.

The synoptic feature that dominated the low-level steering flow was the subtropical ridge to the north. With Cary embedded in the monsoon trough east of Super Typhoon Betty (09W), the initial forecast reasoning was for Cary to track northwestward south of the ridge, closely paralleling the track of Betty (09W). The intensity was expected to increase at a normal rate, but the initial intensification and development of Cary was inhibited by Betty (09W) to the west. As Betty (09W) began to weaken as it crossed the Philippine Islands, Cary's upper-level outflow improved enough to allow development.

Satellite intensity analysis over the next 36-hours indicated that Cary developed rapidly to 90 kt (46 m/sec) at 140600Z. Post-analysis revealed that the satellite-derived intensity estimate ("T-number") was incorrect -

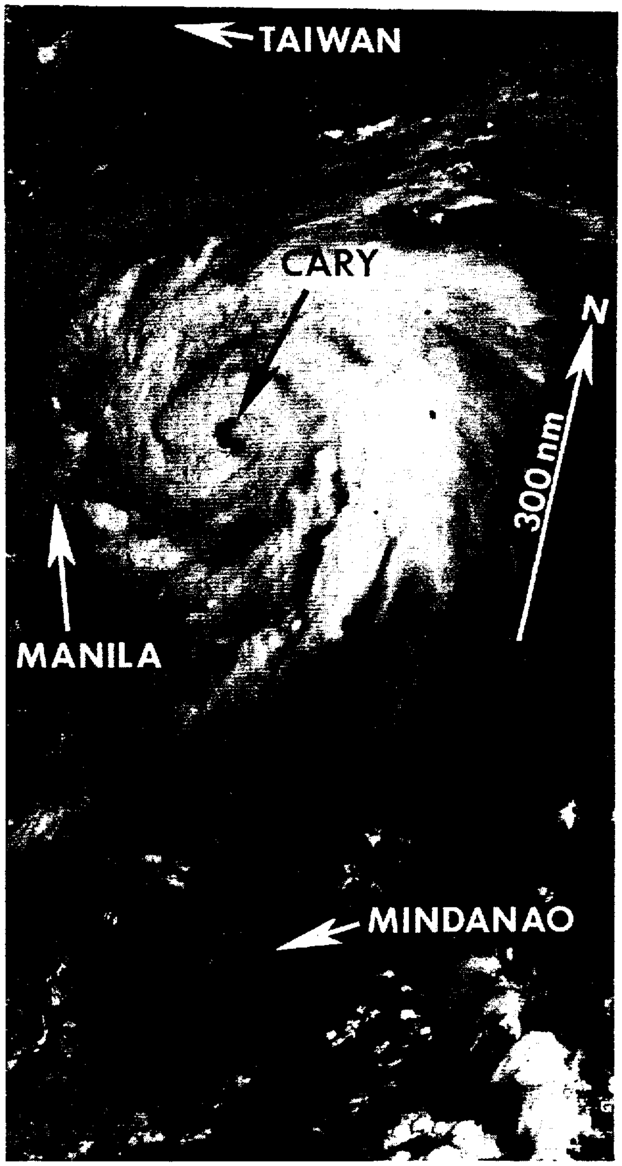


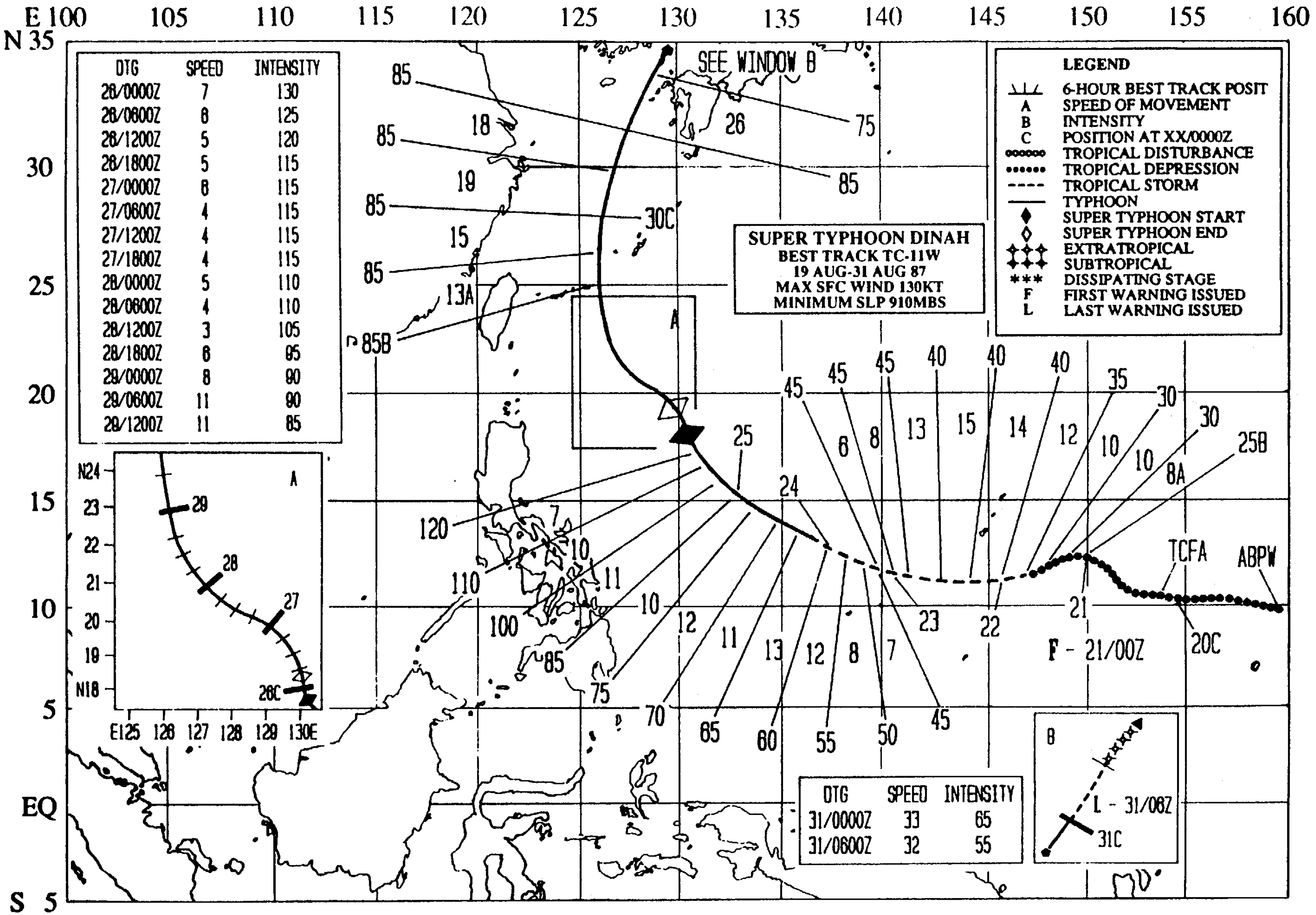
Figure 3-10-3. Typhoon Cary at near maximum intensity and approaching landfall on the island of Luzon (170036Z August DMSP visual imagery).

the diameter of the cold convective cover was misinterpreted as the diameter of a central dense overcast. Aircraft reconnaissance during the same period indicated that Cary was weakening (see Figure 3-10-1). Aircraft reconnaissance at 140029Z reported maximum winds of 50 kt (26 m/sec), however, a minimum sea-level pressure of only 1004 mb was reported, which normally supports only 21 kt (11 m/sec). Aircraft reconnaissance at 141151Z found 850 mb winds of 36 kt (19 m/sec) and an 850 mb height of only 1425 meters, which extrapolated to about 1000 mb surface pressure and surface winds of 30 kt (15 m/sec). The accuracy of the latter fix was especially questionable since the flight-level winds did not support the position in the vortex data message as being the low-level center. Additionally, the Aerial Reconnaissance Weather Officer indicated there was frequent lightning in all quadrants, possible multiple centers and that a penetration of the center was not feasible on this mission. Possibly the 850 mb fix (as indicated on Figure 3-10-2) should have been made about 18 nm (33 km) to the south as shown by the streamline analysis. Also, the excessive scatter (see Figure 3-10-1) of the intensity data acquired by different platforms during this phase of Cary's life is not often observed.

The last scheduled western North Pacific aircraft reconnaissance mission was flown on the 15th of August. At 151405Z, the maximum 700 mb winds reported were 61 kt (31 m/sec), and the 700 mb height was 3007 meters. This corresponds to about a 990 mb surface pressure and 46 kt (24 m/sec) winds. These values represented the strongest winds and lowest pressures found by aircraft reconnaissance on this system. Earlier Dvorak intensity estimates at 150600Z showed winds of 90 kt (46 m/sec). Post-analysis settled on a maximum wind of about 70 kt (41 m/sec) at 151800Z (see Figure 3-10-1).

Cary reached its maximum intensity of 85 kt (44 m/sec) at 170600Z, shortly before making landfall on eastern Luzon (Figure 3-10-3). The intensity dropped from 85 kt (44 m/sec) to 50 kt (26 m/sec) as Cary crossed the Philippine Islands. Extensive flooding was reported in the northern Philippine Islands. There were no reports of casualties.

Cary continued onward across the South China Sea and reintensified to 70 kt (36 m/sec) just southeast of the island of Hainan. The closest point of approach was 15 nm (28 km) to the south of Hainan at 211800Z. Cary then tracked toward the west through the Gulf of Tonkin and swept into northern Vietnam at 221200Z. The final warning was issued at that time. The dissipating system with its residual vorticity and moisture tracked northwestward over land into Burma before finally losing its identity on satellite imagery.


SUPER TYPHOON DINAH
BEST TRACK TC-11W
19 AUG-31 AUG 87
MAX SFC WIND 130KT
MINIMUM SLP 910MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
DTG SPEED INTENSITY
26/0000Z 7 130
26/0600Z 8 125
26/1200Z 5 120
26/1800Z 5 115
27/0000Z 8 115
27/0600Z 4 115
27/1200Z 4 115
27/1800Z 4 115
28/0000Z 5 110
28/0600Z 4 110
28/1200Z 3 105
28/1800Z 8 95
29/0000Z 8 90
29/0600Z 11 90
29/1200Z 11 85
DTG SPEED INTENSITY
31/0000Z 33 65
31/0600Z 32 55
SEE WINDOW B
TCFA
ABPW
F - 21/00Z
L - 31/06Z
31C
30C
20C
26C
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
S 5
N24
23
22
21
20
19
N18
E125
126
127
128
129
130E

SUPER TYPHOON DINAH (11W)

Super Typhoon Dinah (11W), the most destructive typhoon to strike Okinawa and the southern islands of Japan in the past 20 years, caused extensive damage to both Japanese civilian properties and U.S. military bases and assets.

Dinah was first observed on satellite imagery as a disorganized cluster of weak convection in the near-equatorial trough on 18 August. By the 19th, convection became better organized and the disturbance was noted on the Significant Tropical Weather Advisory (ABPW PGTW) issued at 190600Z. During the next eighteen hours, Dinah developed a low-level circulation as it passed northwest of the island of Pohnpei and moved beneath moderate directional and speed divergence at the 200 mb level. The 200000Z satellite imagery indicated weak convective curvature and, as a result, a Tropical Cyclone Formation Alert was issued at 200427Z. During the next eighteen hours, satellite imagery indicated a considerable increase in convection which had become more centralized (see Figure 3-11-1). The system was assigned a Dvorak intensity number ("T-number") of 2.0 which corresponded to maximum sustained surface winds of 30 kt (15

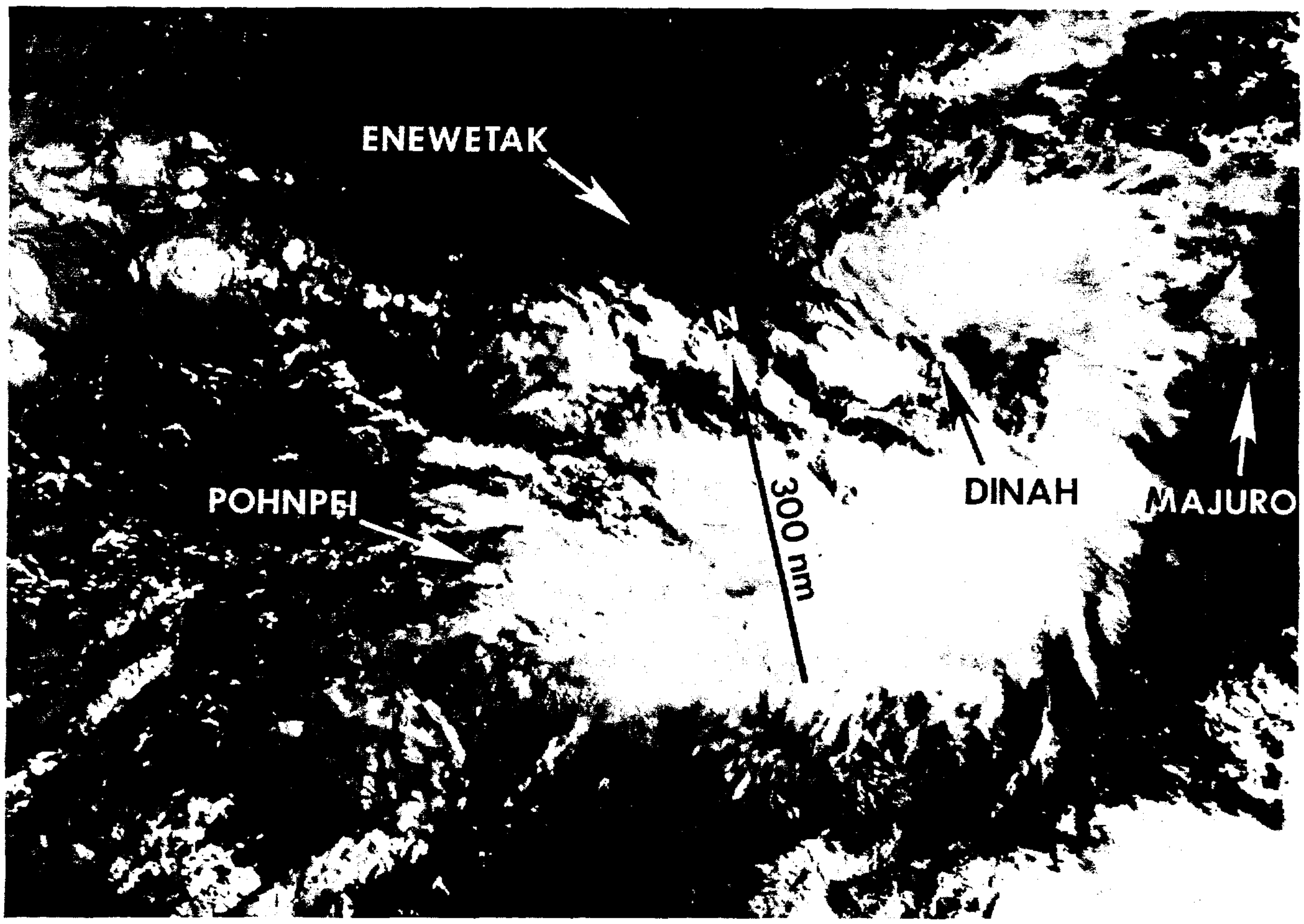


Figure 3-11-1. The initial development of Super Typhoon Dinah was first noted as a considerable increase in the amount of convection (202102Z August NOAA visual imagery).

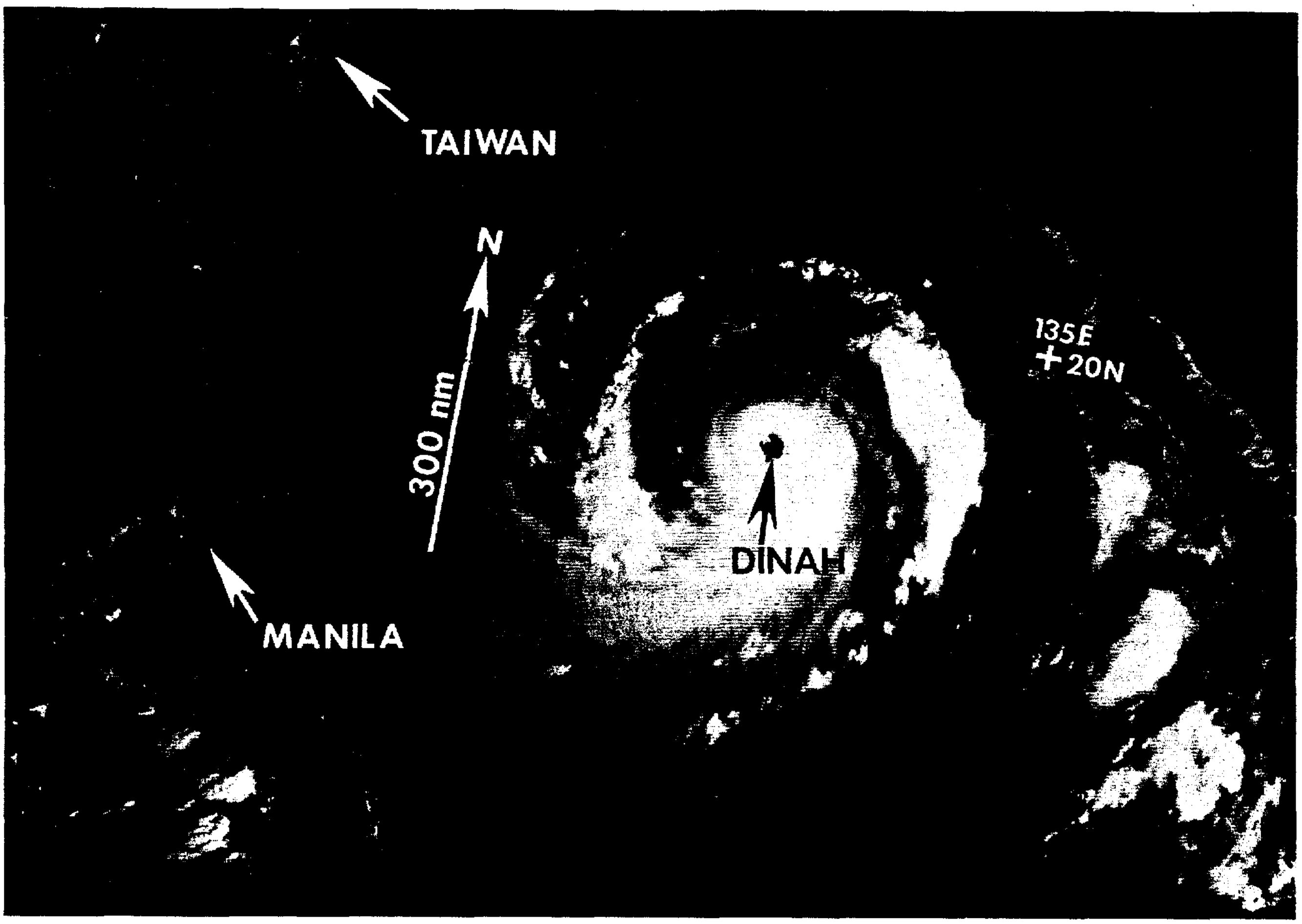


Figure 3-11-2. Super Typhoon Dinah in the Philippine Sea near maximum intensity (260054Z August DMSP visual imagery).

m/sec) and an estimated MSLP of 1000 mb. At 210000Z, the first warning was issued on Tropical Depression 11W when it was located 300 nm (556 km) east-southeast of Guam.

Between 210000Z and 211800Z, Tropical Depression 11W assumed a more westward track in response to the strengthening subtropical ridge to the north and moved beneath an upper-level anticyclone which had associated strong speed divergence southwest of the system. The increased outflow signature on satellite imagery allowed for a Dvorak intensity estimate of 35 kt (18 m/sec). Based on this estimation, Tropical Depression 11W was upgraded to Tropical Storm Dinah (11W) at 211800Z.

Over the next forty-eight hours, Dinah moved westward passing 120 nm (222 km) south of Guam at 220300Z with maximum sustained surface winds estimated at 40 kt (21 m/sec). Dinah did not intensify at the normal rate of one "T-number" per day. This was apparently due to 45 kt (23 m/sec) 200 mb winds over the cyclone which created an undesirable shearing environment. However, by 240000Z, Dinah had moved away from this unfavorable shearing environment and developed a good anticyclonic outflow pattern which was visible on satellite imagery. The 241200Z 200 mb streamline analysis confirmed this and indicated a good cyclonic outdraft directly over Dinah's center which became anticyclonic as it moved radially outward from the center. During the first half of this period, Dinah tracked westward and then gradually turned more toward the west-northwest. JTWC forecasts correctly predicted the system's motion which was supported by the dynamic One-Way Interactive Tropical Cyclone Model (OTCM).

A Dvorak intensity analysis of satellite imagery at 240300Z estimated maximum sustained surface winds of 65 kt (33 m/sec) and an estimated MSLP of 980 mb. On the 240600Z warning, Tropical Storm Dinah was upgraded to typhoon status. At that time it was located 500 nm (926 km) west of Guam. Between 240600Z and 250600Z, Typhoon Dinah's outflow continued to increase with some restriction northwest through northeast of the cyclone which was associated with weak short-wave troughs passing to the north. However, those minor restrictions did not inhibit Dinah from continuing to intensify at the normal Dvorak rate.

During the next twenty-four hours, Typhoon Dinah's intensity increased at a rate much faster than the normal one "T-number" per day and by 260000Z it reached super typhoon intensity (130 kt or 67 m/sec) at a location 500 nm (926 km) east of northern Luzon (see Figure 3-11-2). Dinah remained at super typhoon intensity for only a few hours but maintained maximum sustained surface winds of 110 kt (57 m/sec) or greater until 280600Z.

From 240600Z until 281200Z, Dinah basically tracked toward the northwest at an average forward speed of 11 kt (20 km/hr)

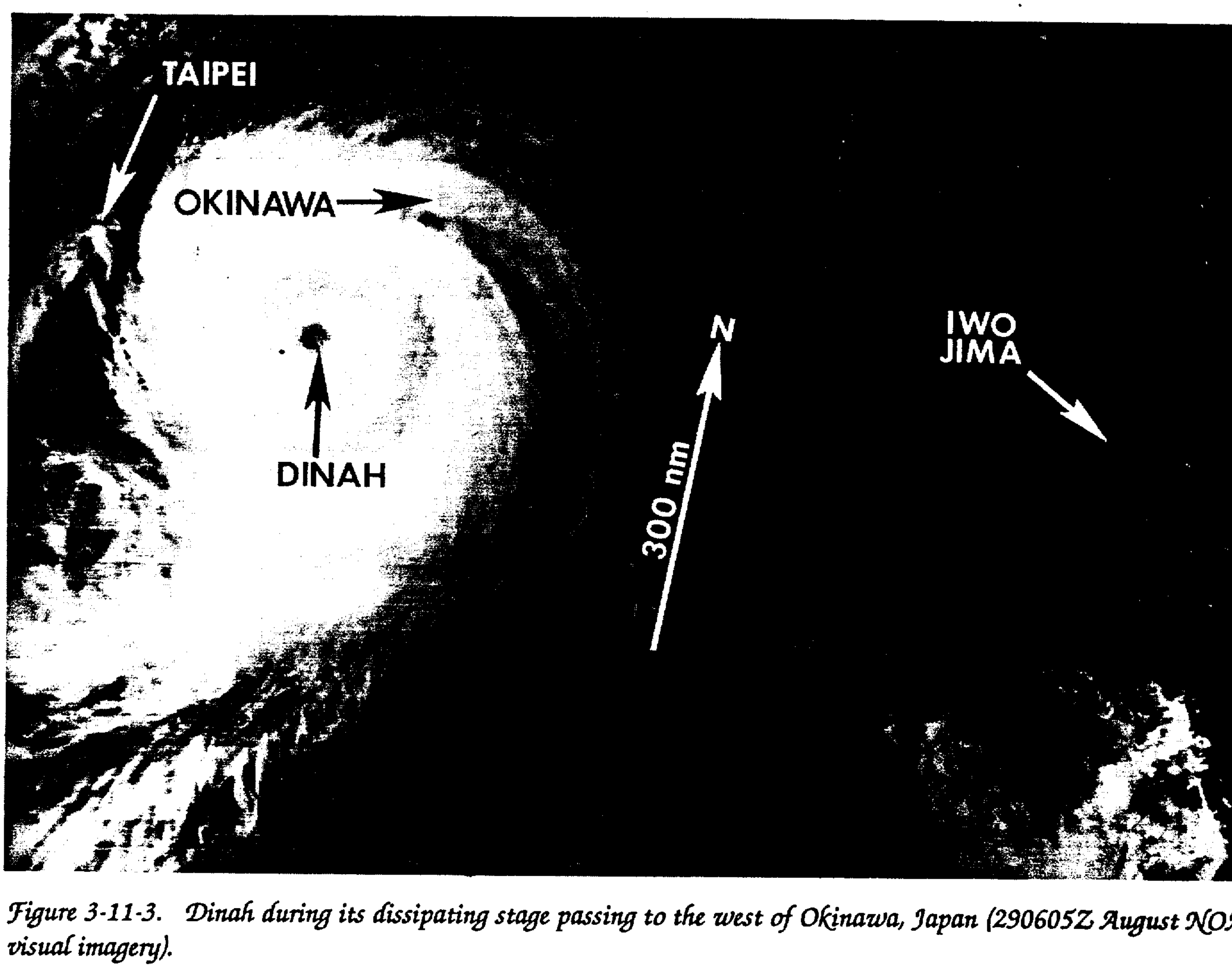


Figure 3-11-3. Dinah during its dissipating stage passing to the west of Okinawa, Japan (290605Z August NOAA visual imagery).

during the first twenty-four hour period, slowing to an average of 6 kt (11 km/hr) by 251800Z. The slower forward speed is typical of a very well-developed and very intense tropical cyclone as it approaches the axis of the subtropical ridge prior to recurvature.

After 281200Z, Typhoon Dinah made a turn toward a more northerly track as it moved around the western periphery of the subtropical high. During the next thirty-six hours, Dinah moved into unfavorable upper-level conditions in the form of impinging mid-level short-wave troughs moving northeastward across eastern China and Japan. As each short-wave trough passed north of Dinah, upper-level wind shear increased and the system's outflow became restricted. As a result, Dinah steadily weakened.

Although Dinah began to weaken after 281200Z (Figure 3-11-3), it still had maximum sustained surface winds of 85 kt (44 m/sec) as it passed 90 nm (167 km) west of Kadena Air Base (Figure 3-11-4) at 291500Z. It caused considerable damage to U.S. military facilities on Okinawa. One person was killed and six people were injured. Trees were uprooted or broken off (Figure 3-11-5), utility poles and lines were blown down, and roofs and suffered structural damage. Total damage estimates to U.S. military facilities on Okinawa were in excess of $1.3 million. Maximum sustained surface winds on Okinawa were 63 kt (32 m/sec) with gusts from 98 to 106 kt (50 to 55 m/sec). Minimum sea-level pressure observed was 983 mb at 291755Z. By 300000Z, Dinah was located 120 nm (222 km) northwest of Okinawa with maximum sustained surface winds estimated to be 85 kt (44 m/sec). A ship passing 30 nm (56 km) northeast of Dinah's center at that time reported sustained winds of 75 kt (39 m/sec) from the southeast and a sea-level pressure of 938.7 mb.

Dinah began to recurve by 300000Z, assumed a north-northeasterly track and accelerated while still maintaining maximum sustained surface winds of 85 kt (44 m/sec). At 301700Z, Typhoon Dinah passed 60 nm (111 km) northwest of Sasebo Naval Base in western

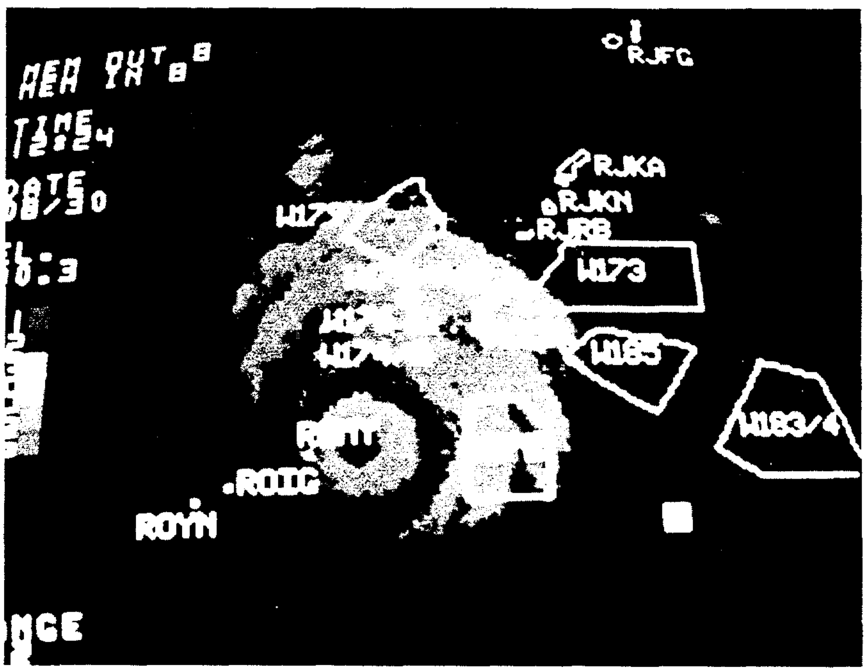


Figure 3-11-4. Radarscope photo of Dinah at 291224Z August (Photo courtesy of Detachment 8, 20 Weather Squadron, Kadena AB, Japan).

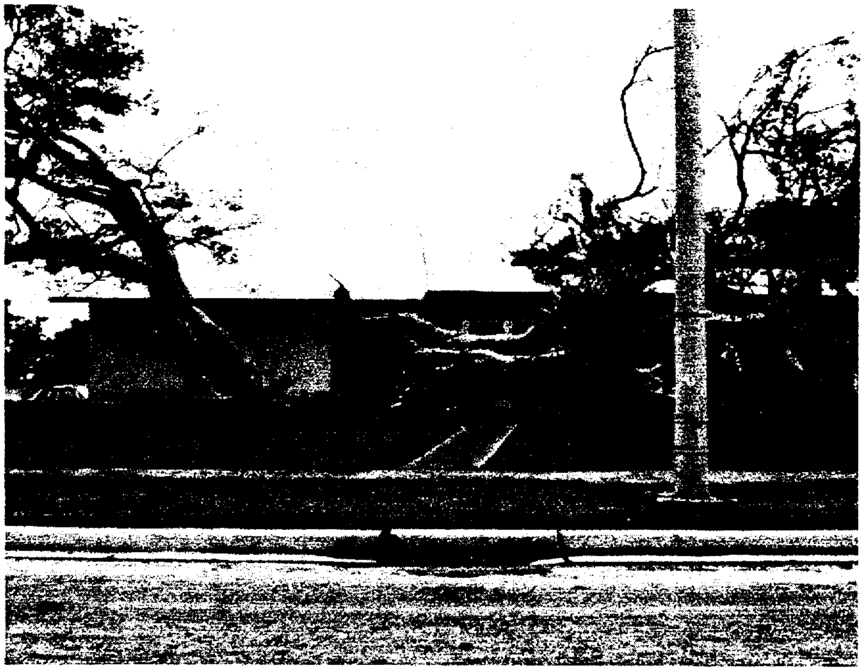
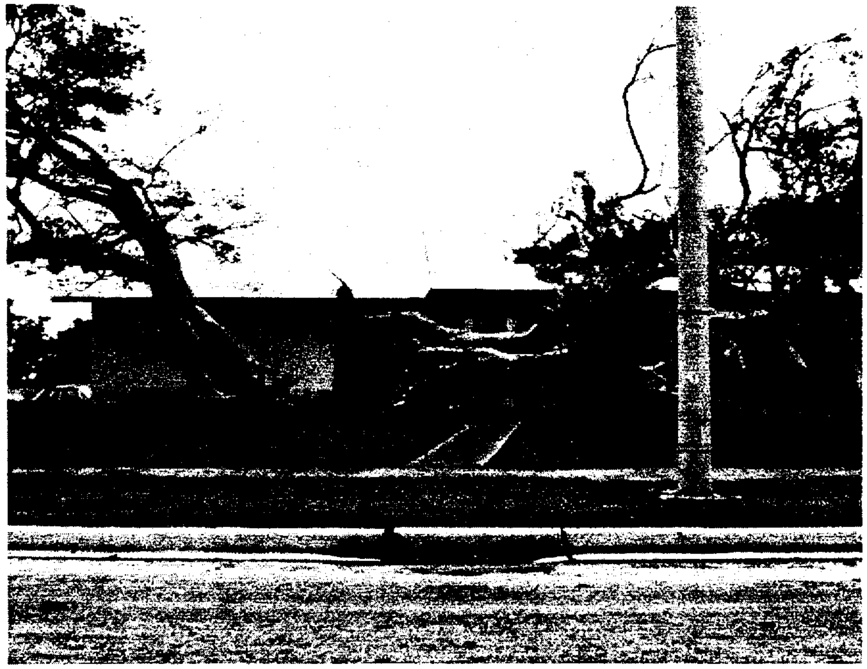


Figure 3-11-5. Trees on Okinawa were damaged and uprooted by the high winds associated with Dinah's passage (Photo courtesy of Detachment 8, 20 Weather Squadron, Kadena AB, Japan).

Japan where maximum sustained surface winds of 60 to 65 kt (31 to 33 m/sec) with gusts to 90 kt (46 m/sec) were observed. Extensive damage was caused by the storm surge and tidal action on seawalls and piers. A landing craft from the USS San Bernardino was destroyed when the seawall eroded and the pier collapsed. Damage also occurred to trees, utility lines and poles, and some building structures. Damage costs to the Japanese Sasebo Navy complex were in excess of $6.7 million, making Dinah the worst tropical cyclone to strike southwest Japan in recent history.

By 310000Z, Dinah was becoming extratropical as it began to merge with a mid-latitude frontal system that extended southwestward across the Sea of Japan. It was beneath the polar jet stream which had winds in excess of 90 kt (46 m/sec). Dinah was downgraded to a tropical storm as its convection sheared off to the northeast. The final warning was issued at 310600Z as the cyclone continued to accelerate toward the northeast at 33 kt (61 km/hr).

Throughout Dinah's life, JTWC consistently forecast recurvature and acceleration toward the northeast through the Sea of Japan. Forecast track errors were smaller than average. The dynamic aid OTCM performed extremely well during recurvature, while the objective aids Half Persistence and Climatology (HPAC) and climatology were used extensively as Dinah passed beneath the subtropical ridge.



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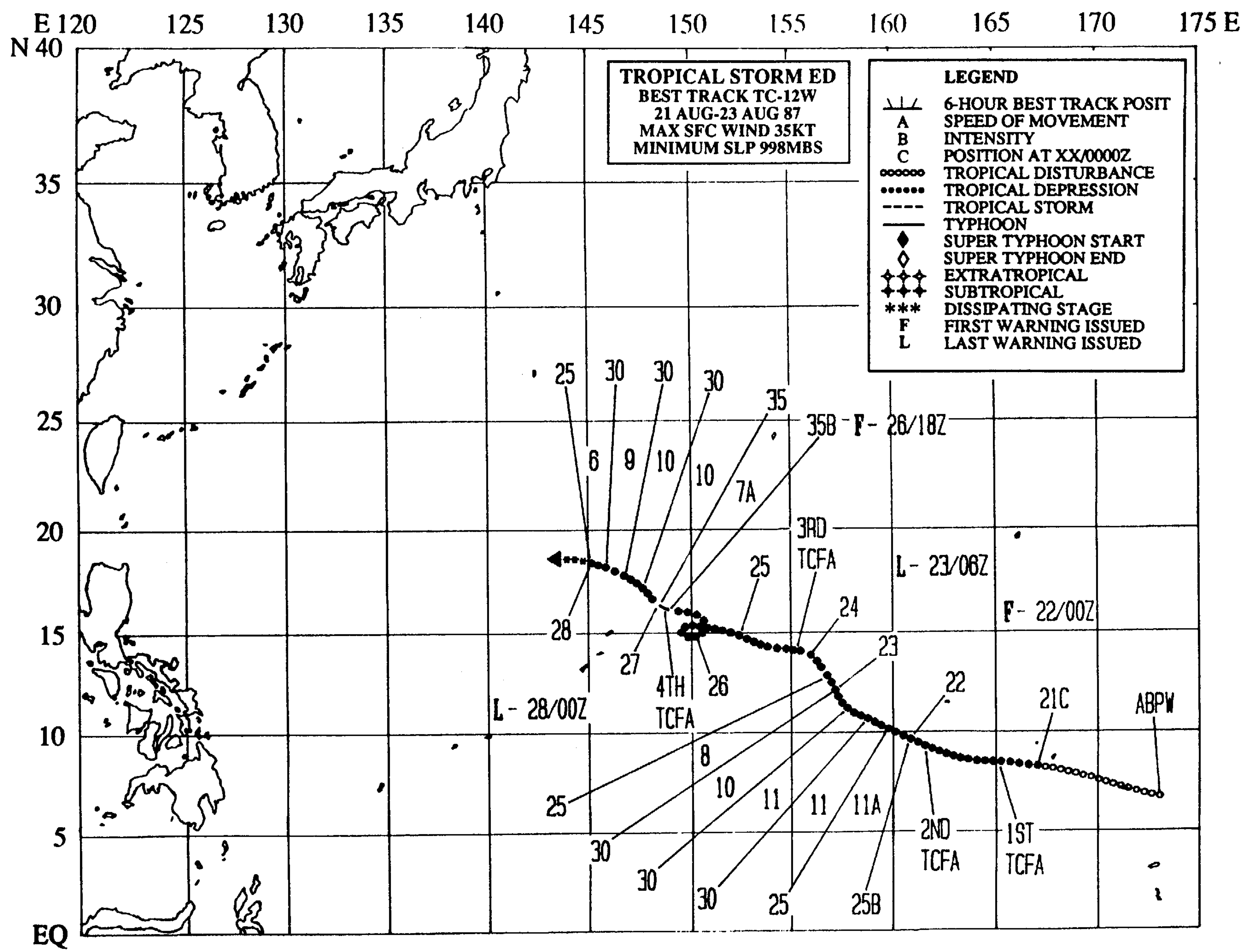

TROPICAL STORM ED
BEST TRACK TC-12W
21 AUG-23 AUG 87
MAX SFC WIND 35KT
MINIMUM SLP 998MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
F - 26/18Z
L - 23/06Z
F - 22/00Z
L - 28/00Z
3RD TCFA
4TH TCFA
2ND TCFA
1ST TCFA
ABPW
21C
35B
25B
7A
11A

TROPICAL STORM ED (12W)

Tropical Storm Ed (12W) was the third of four significant tropical cyclones that occurred during the month of August. Ed was a difficult system for JTWC to locate and forecast because of its fluctuations in intensity, speed and track direction, and its poorly defined cloud signature.

Ed formed during the third week of August in the western North Pacific monsoon trough about 90 nm (167 km) east of the island of Majuro in the Marshalls. It was first detected as an area of persistent convection with a coincident weak low-level cyclonic circulation. This suspect area appeared on the Significant Tropical Weather Advisory (ABPW PGTW) at 200600Z. For the next 24-hours, the disturbance moved rapidly at a speed of 17 to 23 kt (32 to 43 km/hr) toward the west-northwest. Improved upper-level outflow and increased central convection prompted the first Tropical Cyclone Formation Alert (TCFA) at 210600Z.

At 212130Z, a second TCFA was issued to supersede the first TCFA, since the disturbance was moving out of the original alert

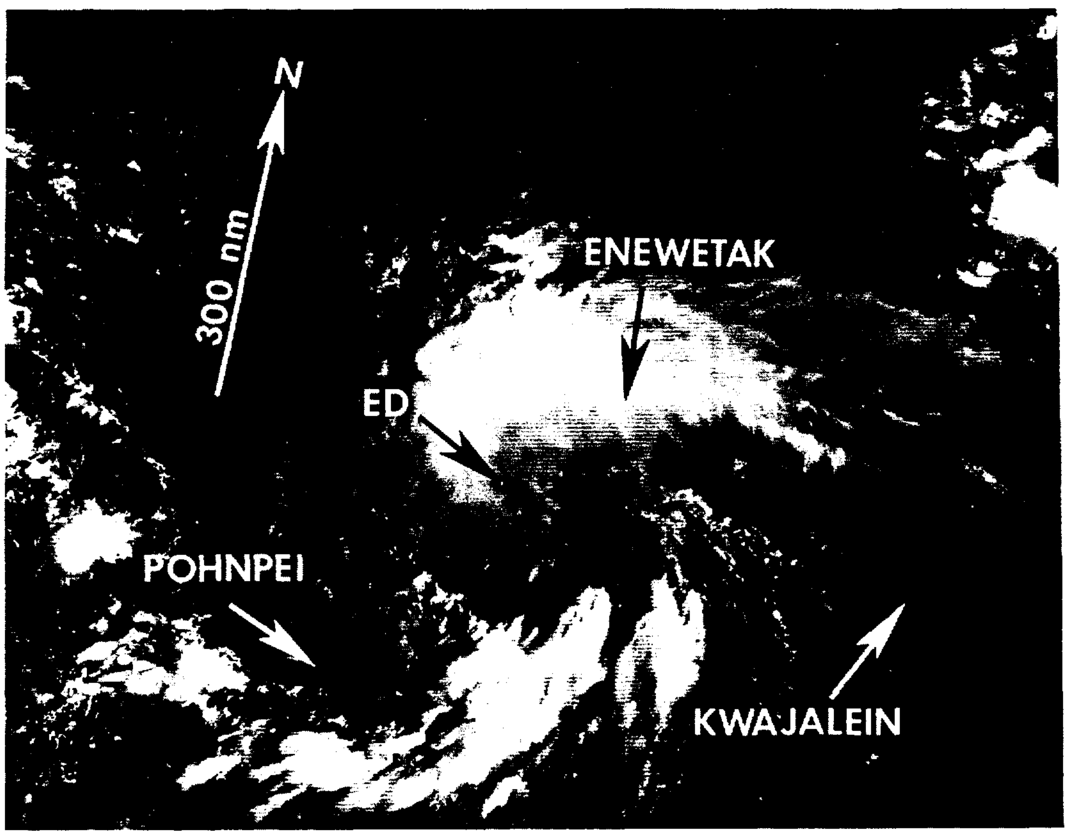


Figure 3-12-1. Formative stage of Tropical Storm Ed (212253Z August DMSP visual imagery).

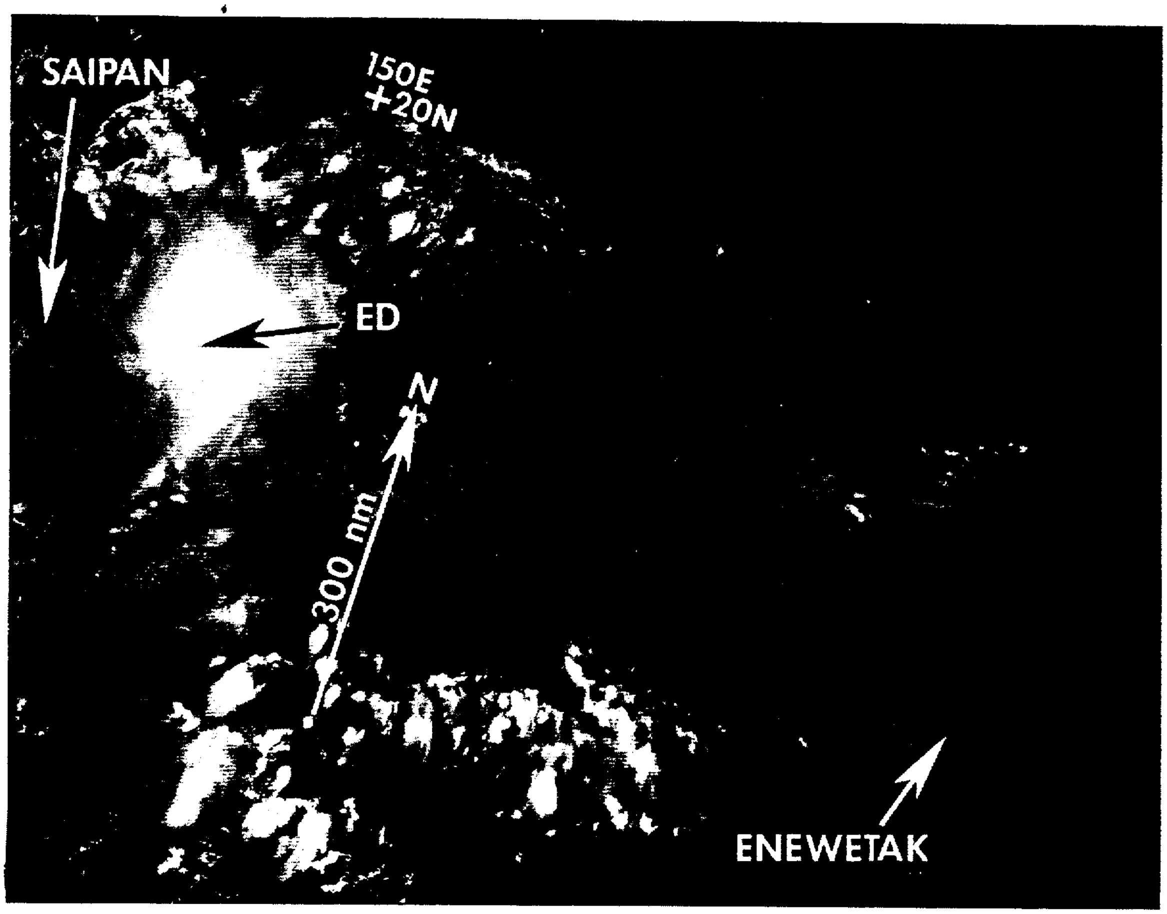


Figure 3-12-2. The regenerated Tropical Depression 12W shortly before it was upgraded once more to Tropical Storm Ed (262252Z August DMSP visual imagery).

area. The disturbance continued on a west-northwestward track at slightly lower speeds of 14 to 17 kt (26 to 32 km/hr).

Visual satellite imagery (Figure 3-12-1) showed tighter curvature of the convective cloud lines and increased cirrus outflow to the north. Also, drifting buoys in the area indicated surface wind speeds of 25 to 30 kt (13 to 15 m/sec). As a result, at 220000Z the second TCFA was upgraded to Tropical Depression 12W. Unexpectedly, thirty-hours later Tropical Depression 12W showed significantly decreased convection and system organization on satellite imagery. Consequently, a final warning was issued. The tropical disturbance was then placed on the ABPW PGTW and monitored for signs of future regeneration.

Ed did maintain its low-level identity even as Typhoon Dinah (11W), which was further to the west, was increasing the vertical shear aloft over it. Finally, a ragged central dense overcast persisted and the system's upper-level outflow redeveloped. The third TCFA followed at 240800Z. However, by 250600Z, the TCFA was cancelled when the upper-level outflow from Super Typhoon Dinah (11W), located to the west, increased its shearing effect on Ed which caused the convection to significantly decrease.

At 262030Z, a fourth TCFA was issued when cloudiness associated with the disturbance flared-up again. Satellite intensity analysis (Dvorak, 1984) estimated the intensity of the system at 35 kt (18 m/sec). This TCFA was almost immediately upgraded as Tropical Depression 12W, with a valid time of 261800Z, based on the receipt of a new satellite picture, which indicated that the disturbance had been developing more rapidly than previously expected (see Figure 3-12-2).

The regenerated Tropical Depression 12W was further upgraded to tropical storm intensity at 270000Z. This upgrade was based on the Dvorak satellite intensity analysis at 261800Z, that indicated 35 kt (18 m/sec) sustained surface winds. In addition, at 270600Z, Tropical Storm Ed's position was relocated on the warning due to the formation of a 60 nm (111 km) diameter central dense overcast from a central cold cover. As a result, Ed's center location was moved 45 nm (83 km) farther north. Later, at 271200Z, Tropical Storm Ed (12W) was relocated a second time when satellite fixes revealed that the system had moved 75 nm (139 km) further north than previously forecast. When the central convection was finally stripped away from the low-level circulation, the last warning was issued at 280000Z (see Figure 3-12-3).

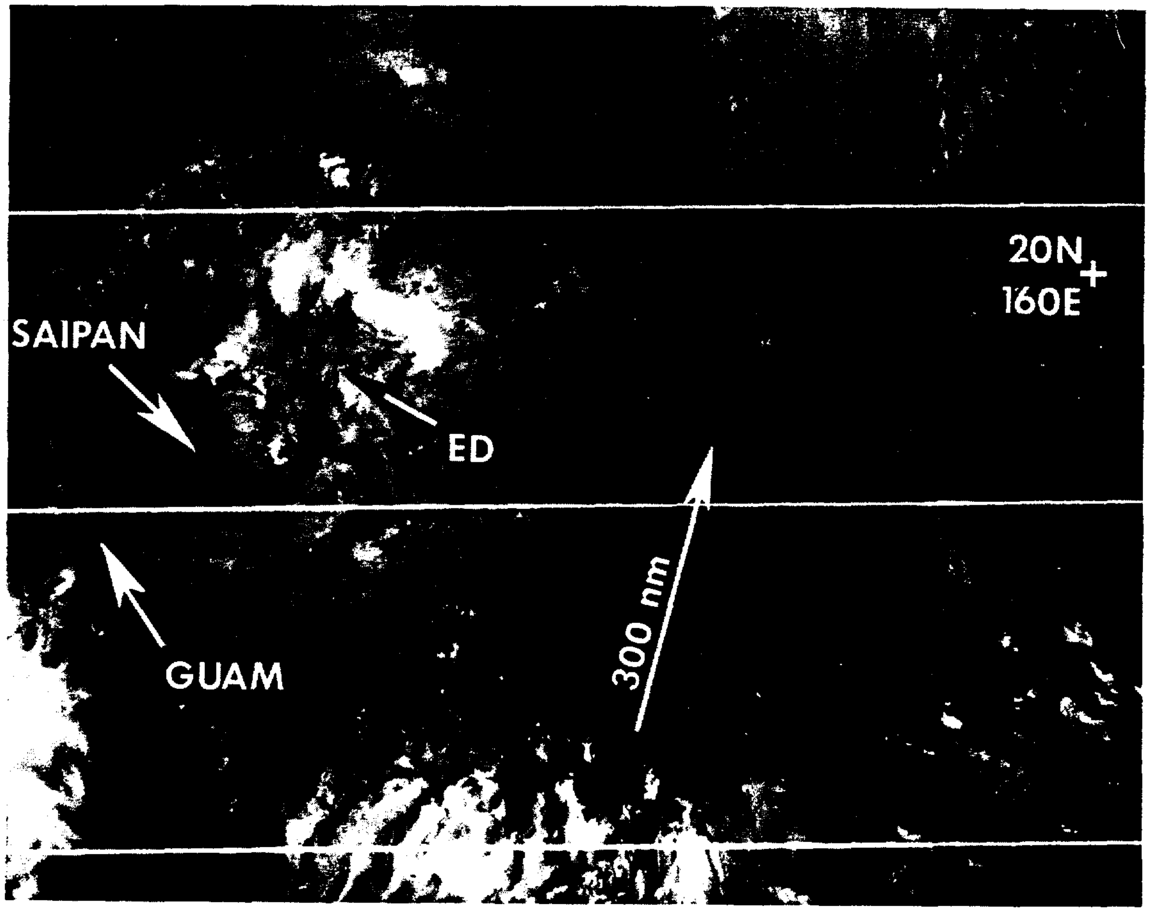
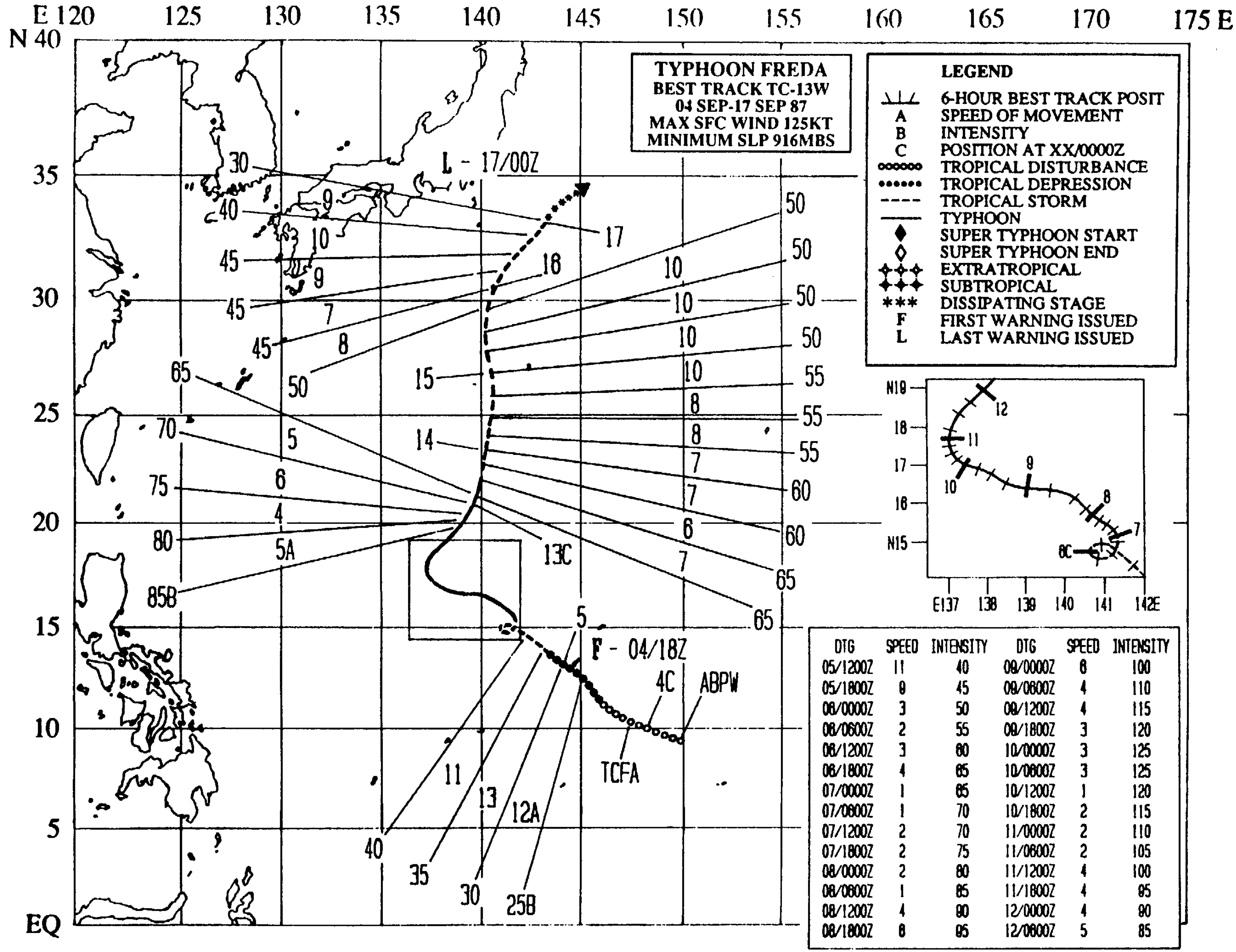


Figure 3-12-3. Tropical Storm Ed (12W) after the system had shed its central dense overcast (270445Z August NOAA visual imagery).



DTG	SPEED	INTENSITY	DTG	SPEED	INTENSITY
05/1200Z	11	40	09/0000Z	6	100
05/1800Z	8	45	09/0600Z	4	110
06/0000Z	3	50	09/1200Z	4	115
06/0600Z	2	55	09/1800Z	3	120
06/1200Z	3	60	10/0000Z	3	125
06/1800Z	4	65	10/0600Z	3	125
07/0000Z	1	65	10/1200Z	1	120
07/0600Z	1	70	10/1800Z	2	115
07/1200Z	2	70	11/0000Z	2	110
07/1800Z	2	75	11/0600Z	2	105
08/0000Z	2	80	11/1200Z	4	100
08/0600Z	1	85	11/1800Z	4	95
08/1200Z	4	90	12/0000Z	4	90
08/1800Z	6	95	12/0600Z	5	85

TYPHOON FREDA (13W)

Freda was the first of seven significant tropical cyclones to develop during the month of September and the middle tropical cyclone (geographically) of three systems that developed at nearly the same time; namely Freda, Typhoon Gerald (14W) and Super Typhoon Holly (15W). During this three tropical cyclone outbreak, individual development and movement trends were very similar even though the systems were never closer together than 900 nm (1667 km). Freda was unusual because although it traversed less than 10 degrees of longitude while in warning status, it moved northward for almost twenty-five degrees of latitude. Freda's thirteen day life span and fifty warnings were WESTPAC records for 1987.

Figure 3-13-1. First appearance of Freda's eye (061723Z September NOAA infrared imagery).

Freda developed in an active monsoon trough. The disturbance first appeared as a persistent cluster of convection in the eastern Caroline Islands on the 1st of September. Due to the persistent convective activity it was mentioned as a new suspect area on the 030600Z Significant Tropical Weather Advisory (ABPW PGTW). A low-level cyclonic circulation was apparent in the synoptic surface/gradient-level data beginning at 031200Z. By 040000Z, synoptic data indicated winds of 20 to 30 kt (10 to 15 m/sec). Satellite intensity analysis (Dvorak, 1984) estimated maximum sustained surface winds of 25 kt (13 m/sec). These data, plus a distinct gradient-level circulation and a 3 mb pressure fall over the past 24-hours (to a minimum of 1003 mb) supported a Tropical Cyclone Formation Alert issued at 040357Z.

With the tropical disturbance just southeast of Guam, there was heightened concern about intensification as the system moved into an area of decreased vertical shear. During the night, infrared satellite images showed a flaring of convection, rapidly expanding cirrus outflow and a speedy displacement of the cloud system toward the west. Satellite analysis at 041745Z estimated maximum sustained surface winds of 30 kt (15 m/sec) and supported the issuance of the first warning on Tropical Depression 13W at 041800Z. (This was also the time JTWC went to warning on Tropical Depression 14W.) Within six hours, after the first visual satellite imagery provided a better look, Tropical Depression 13W was relocated 215 nm (398 km) east-southeast of the earlier expected position. Warning number two included the amplifying remarks:

> *Satellite imagery over the past six hours for Tropical Depression 13W indicate that the feature previously tracked on infrared imagery, has weakened, hence the system has been relocated. The latest visual imagery shows low-level cloud lines placing the low-level circulation center substantially further to the east than previously expected. This also indicates a slower forward speed.*

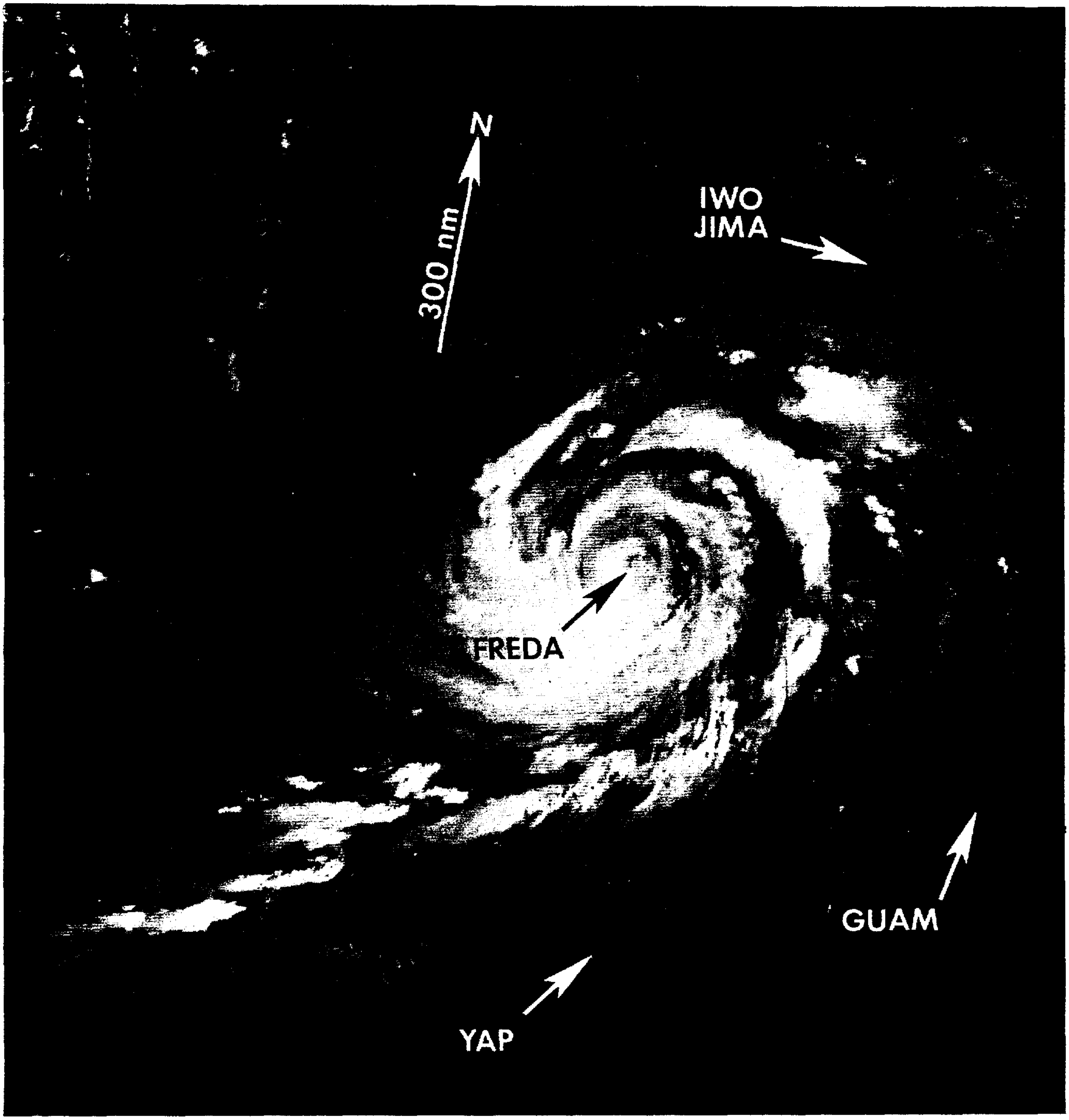


Figure 3-13-2. Typhoon Freda near maximum intensity. Note the elongation of the cloud system from east-northeast to west-southwest (110030Z September DMSP visual imagery).

Freda passed approximately 30 nm (56 km) southwest of Guam while moving northwestward at 14 kt (26 km/hr) with an estimated intensity of 25 to 30 kt (13 to 15 m/sec). Once past Guam, Freda developed rapidly and was upgraded to tropical storm intensity at 050600Z. (It was at this time that JTWC also began warning on Tropical Depression 15W, thus creating the second three-storm warning situation of the year.)

Suddenly, twelve-hours later, Freda appeared to become quasi-stationary at a position approximately 250 nm (463 km) to the

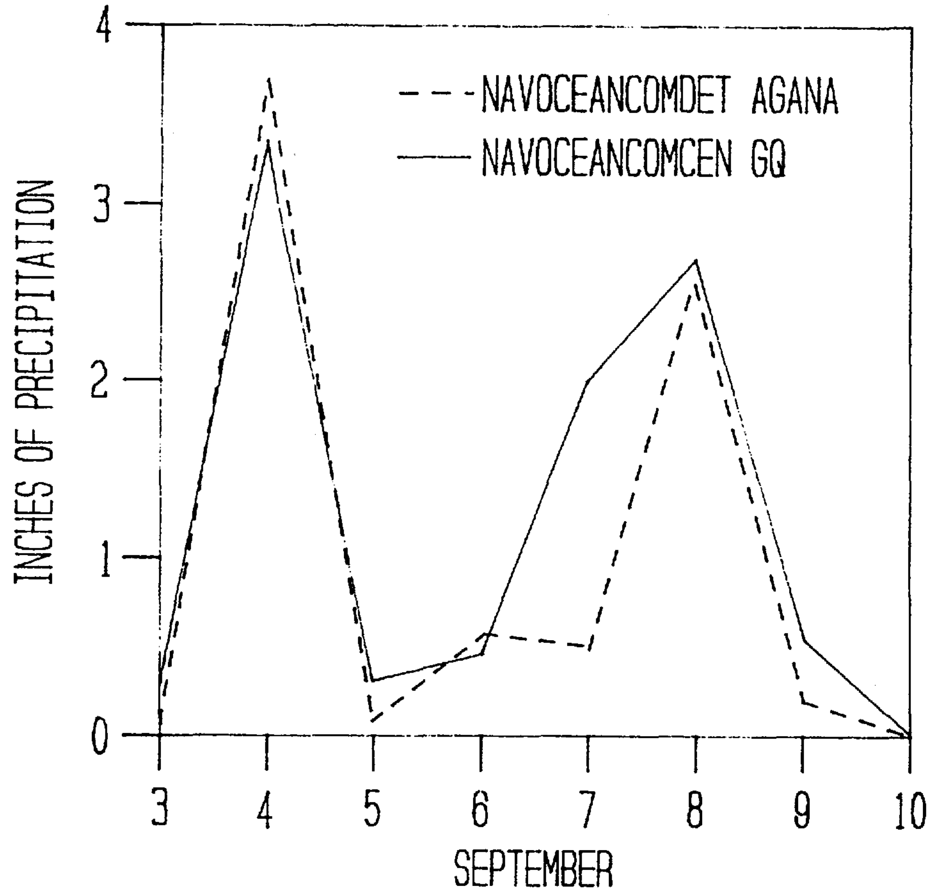


Figure 3-13-3. Plot of the daily amounts of precipitation at two recording stations on Guam as spiral convective arms from Freda passed over the island.

west-northwest of Guam. This was also the same time that Tropical Storm Gerald (14W) became quasi-stationary. The two systems were approximately 900 nm (1667 km) apart at that time.

With the appearance of a small ragged eye on satellite imagery at 061723Z (see Figure 3-13-1), Freda was upgraded to typhoon intensity. After executing a tight cyclonic loop, Freda began to move slowly westward on the 8th. Then, on the 10th, Freda slowed and started a tight turn toward the northeast. Concurrently with the track change, Freda reached an estimated peak intensity of 125 kt (64 m/sec), based on Dvorak satellite intensity analysis. Figure 3-13-2 shows Freda early on the 11th as it rounds the western periphery of the subtropical ridge. Note the elongation of the cloud system into an east-northeast/west-southwest orientation. This asymmetry is a consequence of adjustments between the tropical cyclone and the ambient flow. (One day prior to Freda's change in track toward the north, Super Typhoon Holly (15W) also moved northward. At 091200Z, the two systems were approximately 1080 nm (2000 km) apart. Super Typhoon Holly (15W) had been steadily moving closer to Freda from the east prior to the northward bends in their tracks.)

During this prolonged northward trek, a consequence of the intense monsoonal trough and the absence of a strong subtropical ridge, Freda started to slowly accelerate and weaken. At 1800Z on the 13th, Freda was downgraded to tropical storm intensity.

On the 16th, Freda began to interact with an eastward-moving, mid-level trough passing to the north of the system. This interaction resulted in a curved track toward the northeast. As a result, Freda missed the southeastern tip of Honshu by approximately 180 nm (333 km). Shortly thereafter, Freda began extratropical transition as vertical wind shear increased and the system entrained dry, cool, mid-latitude air. The last warning was issued by JTWC at 170000Z as the system accelerated toward the northeast.

Guam received two distinct heavy periods of rain over five days when Freda stalled to the west (Figure 3-13-3). Specifically

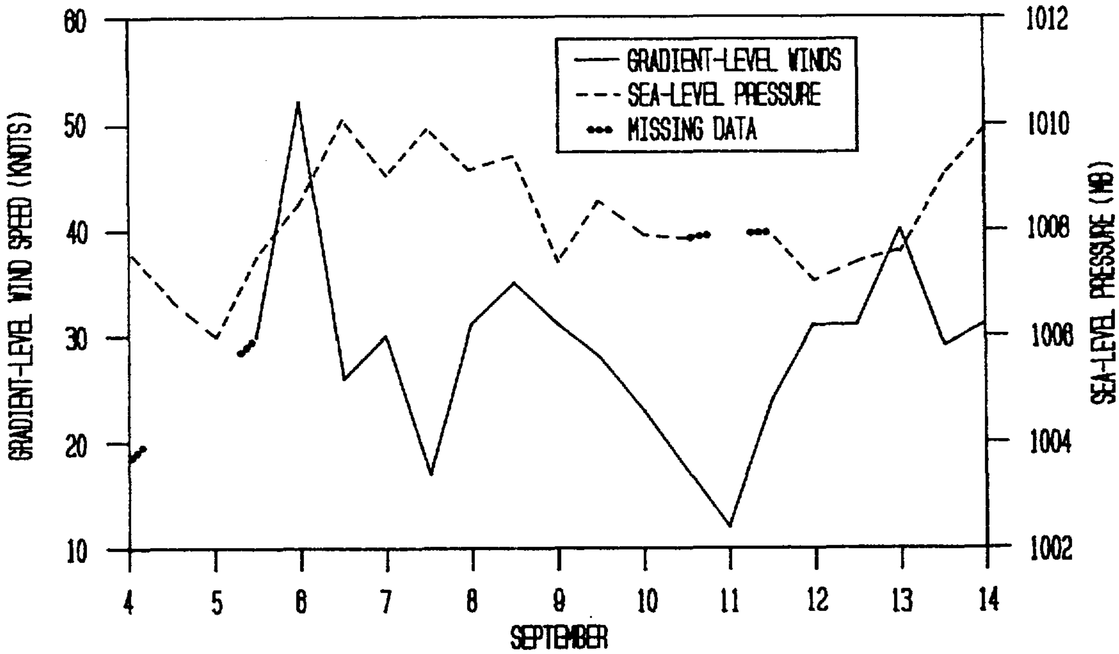
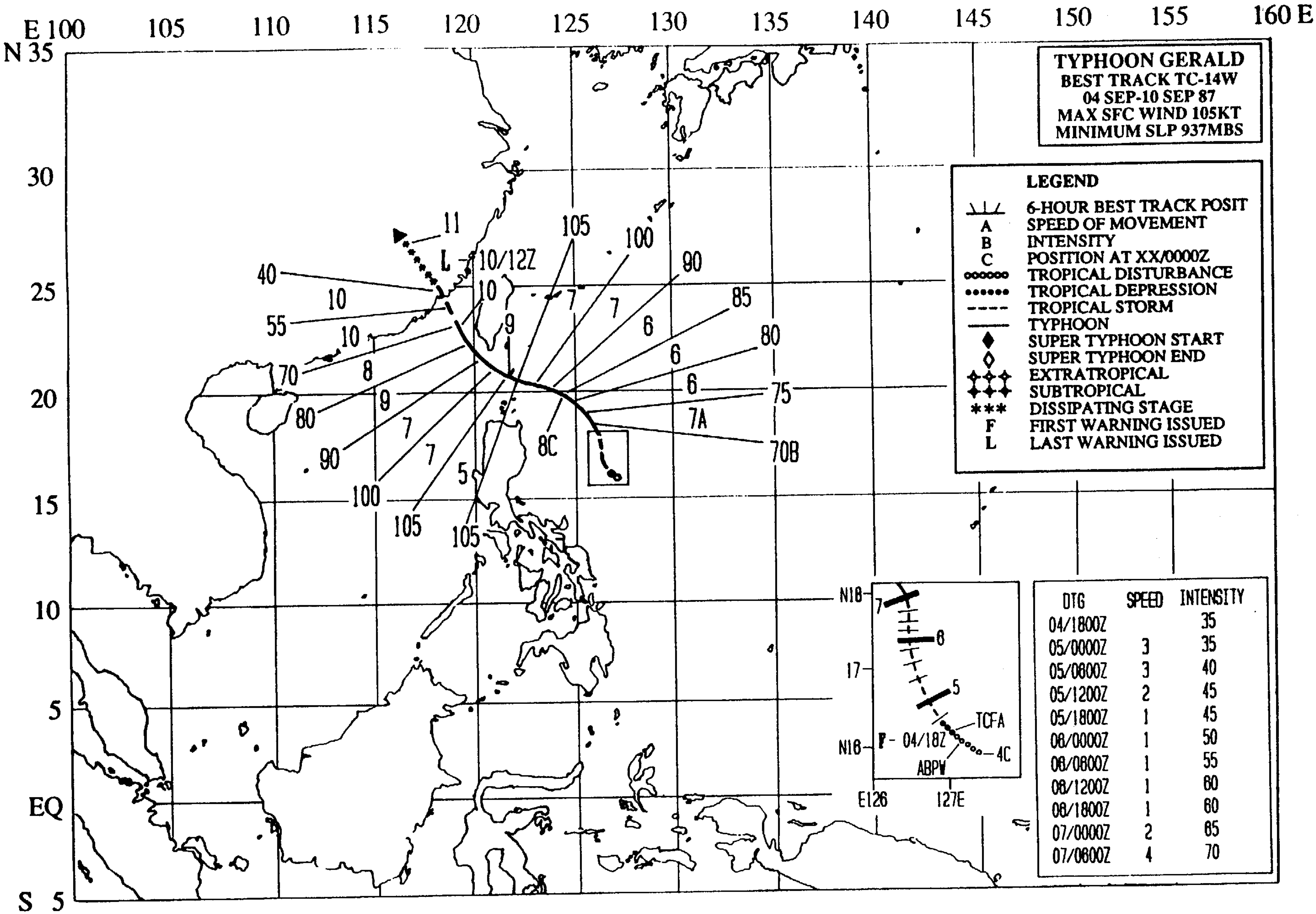


Figure 3-13-4. Gradient-level wind speeds and sea-level pressure on Guam as Freda stalled southwest of the island. The period of lighter winds from the 10th through the 11th was associated with the proximity of the zone of low-level speed convergence (convergent asymptote) between Freda and Super Typhoon Holly (15W).

on the 4th of September, when Freda was close by NAVOCEANCOMCEN/JTWC located on Nimitz Hill, Guam received 3.35 in (8.51 cm) of precipitation, and the Naval Oceanography Command Detachment at the Naval Air Station Agana, a few miles further north, received 3.75 in (10.93 cm). On the 8th, over 2.5 in (6.35 cm) of rain fell on Guam as convection associated with a spiral band passed overhead. Due to the proximity of Freda, and later Super Typhoon Holly (15W), Guam experienced periods of gales from the south-southwest to west-southwest for nearly 10 days (from the 5th through the 14th) (Figure 3-13-4). The strongest observed winds reported during this period were the 40 kt (21 m/sec) southwesterly gradient-level winds at 121200Z. The resulting high seas and hazardous surf through the Marianas disrupted shipping, destroyed seawalls, damaged reefs, eroded beaches and stranded islanders; but fortunately no lives were lost.



TYPHOON GERALD
BEST TRACK TC-14W
04 SEP-10 SEP 87
MAX SFC WIND 105KT
MINIMUM SLP 937MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
DTG SPEED INTENSITY
04/1800Z 35
05/0000Z 3 35
05/0600Z 3 40
05/1200Z 2 45
05/1800Z 1 45
06/0000Z 1 50
06/0600Z 1 55
06/1200Z 1 60
06/1800Z 1 60
07/0000Z 2 65
07/0600Z 4 70
10/12Z
TCFA
04/18Z
ABPW
E126
127E
N18
17
N16
E 100 105 110 115 120 125 130 135 140 145 150 155 160 E
N 35 30 25 20 15 10 5 EQ S 5

TYPHOON GERALD (14W)

Typhoon Gerald developed in early September in an active monsoon trough at the same time that Typhoons Freda (13W) and Holly (15W) were intensifying further to the east. Gerald was unique in that it matured within the monsoon trough and did not detach from it. The most distinctive feature of Gerald was an unusually large eye.

After Typhoon Dinah (11W) moved northward through the East China Sea and became extratropical in the Sea of Japan, the minimum sea-level pressures (MSLPs) east of the Philippine Islands remained slightly lower (1005 mb) than the seasonal mean of 1007 mb. This below normal low-pressure area was not mentioned as a suspect area on the Significant Tropical Weather Advisory (ABPW PGTW) until 020600Z September, when persistent convection appeared.

A Tropical Cyclone Formation Alert (TCFA) at 020830Z upgraded the suspect area in the Philippine Sea after a sudden flare-up of convection within the cloud system. Almost immediately the central convection fell apart as the poleward edge of the cirrus outflow flattened, restricted by the amplification of a mid-latitude trough to the north. Cancellation of the first TCFA on the monsoon depression area followed at 030800Z (Figure 3-14-1). The arrested development of the monsoon

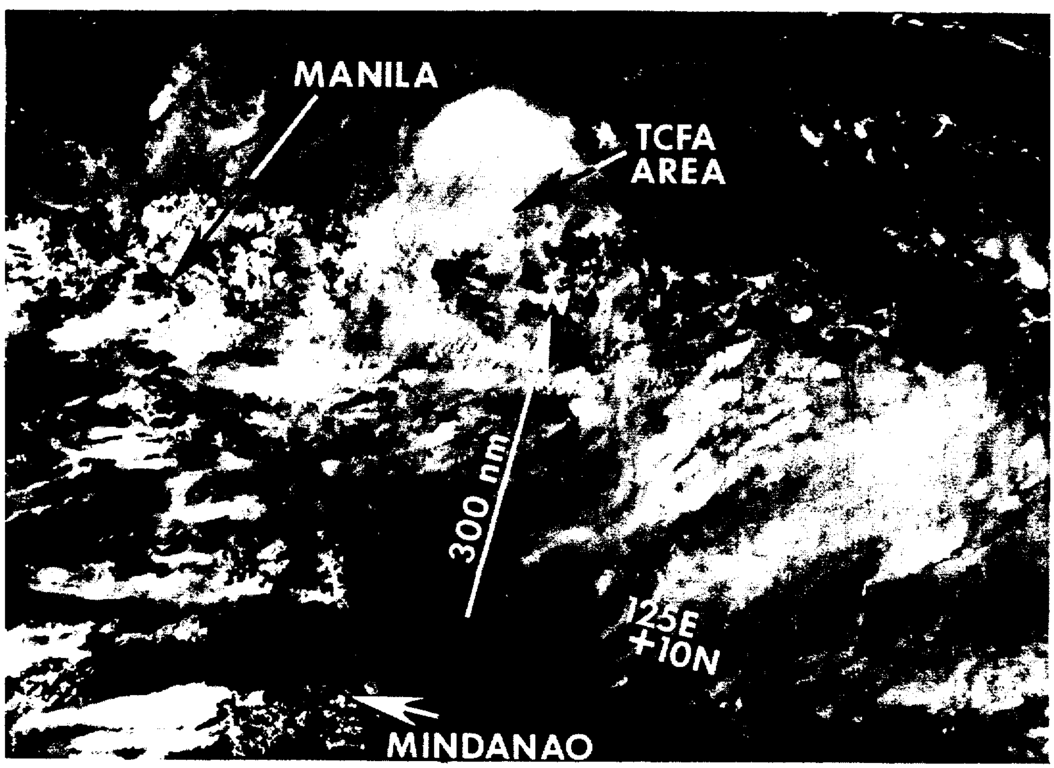


Figure 3-14-1. A broad band of cloudiness associated with the southwest monsoon extends eastward across the central Philippine Islands (030653Z September NOAA visual imagery).

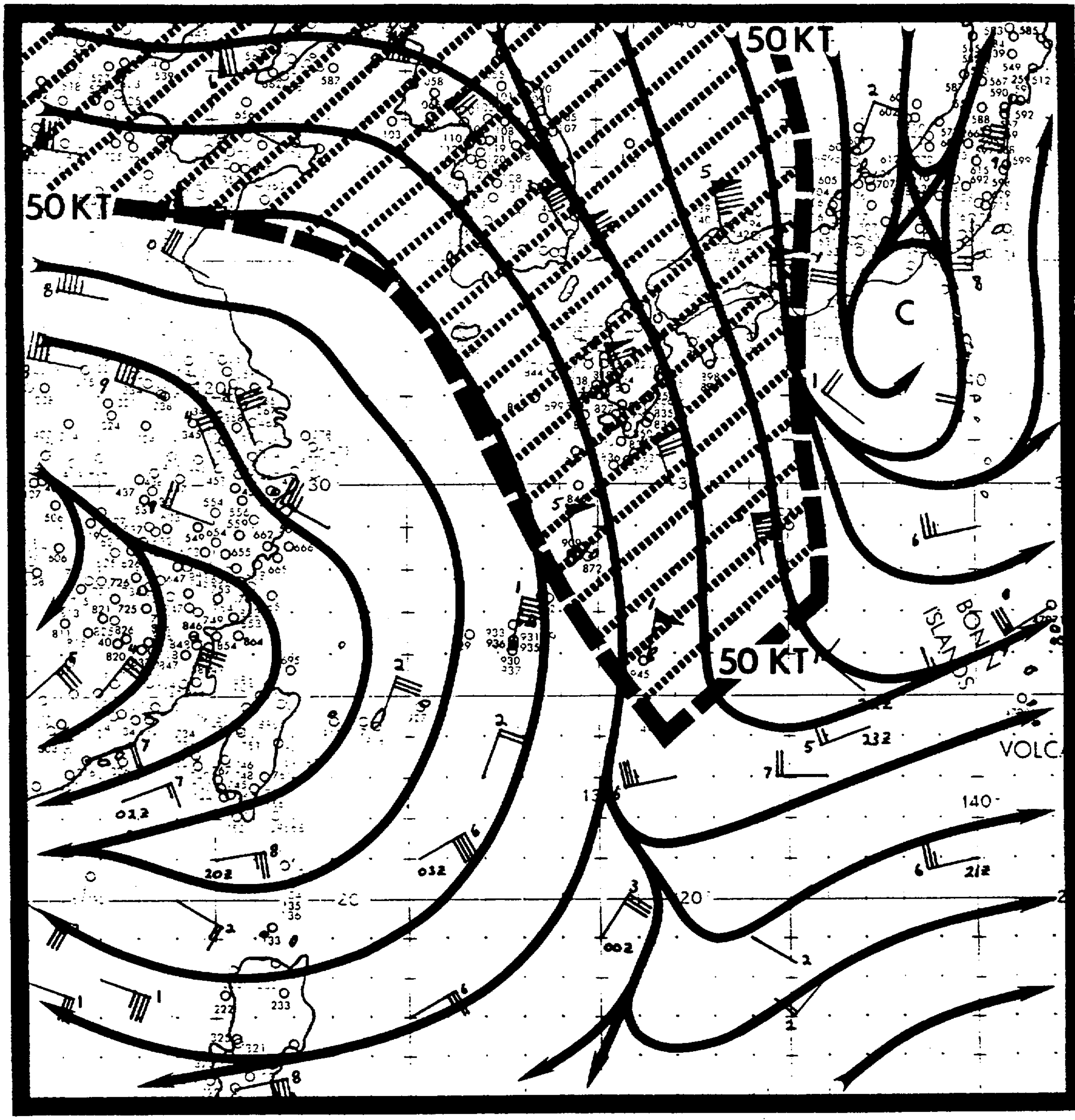


Figure 3-14-2. The 200 mb analysis at 040000Z September revealed a wind speed maximum across southwestern Japan.

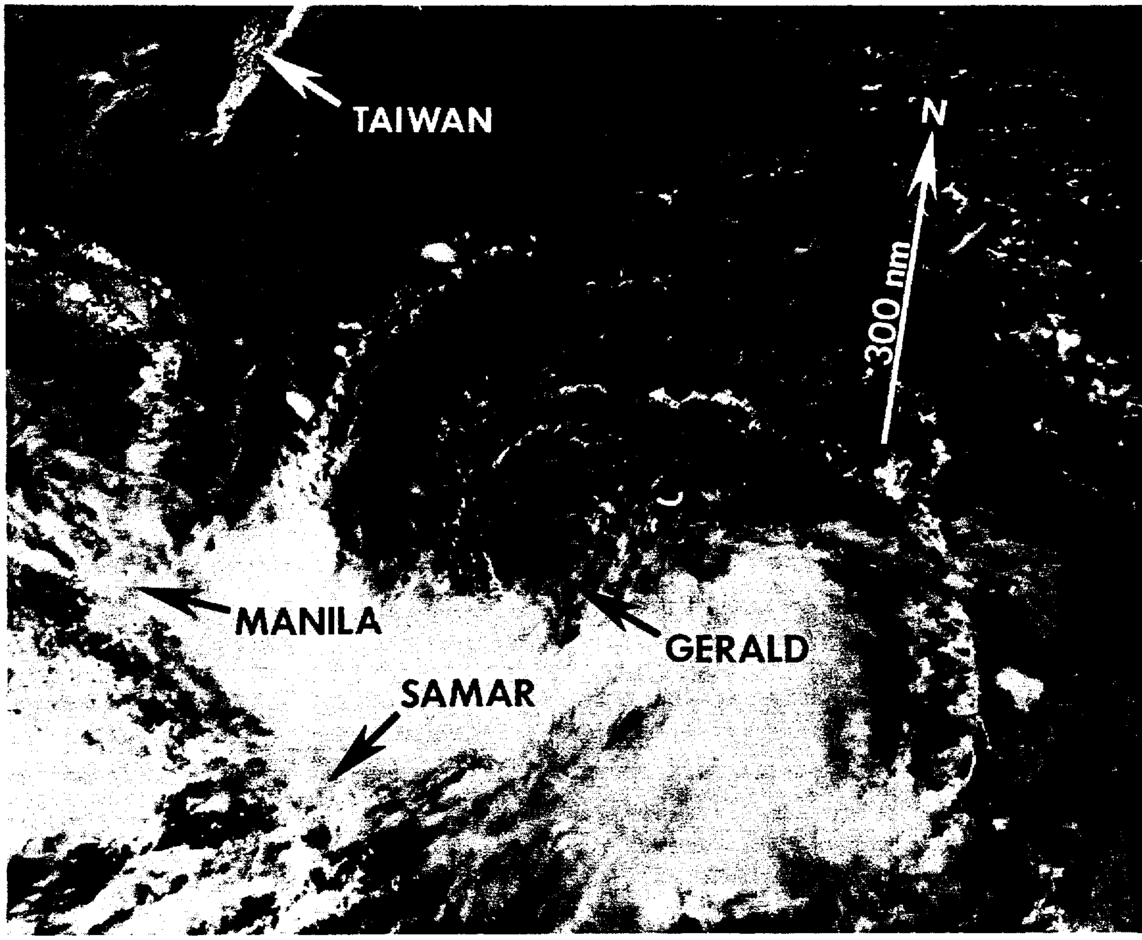


Figure 3-14-3. Due to northerly flow aloft, convection associated with the low-level circulation center was confined to the southern semicircle (040642Z September NOAA visual imagery).

depression appears to be related to the movement of an upper-level wind maximum across the island of Kyushu, Japan. This resulted in an increase in northerly flow over the northern Philippine Sea (Figure 3-14-2). This increased upper-level wind shear was responsible for delaying Gerald's development beyond the monsoon depression stage.

At 040600Z, synoptic data obtained from drifting buoy and ship reports indicated the MSLP had dropped to 1003 mb with 25 to 30 kt (13 to 15 m/sec) winds near the circulation center. Satellite imagery also showed an exposed low-level circulation was displaced slightly to the north of a single major convective band (Figure 3-14-3). These data prompted the issuance of a second TCFA at 041000Z. The first warning on Tropical Depression 14W followed at 041800Z, supported by a Dvorak intensity estimate of 30 kt (15 m/sec) and a drifting buoy report of a 1001 mb that revealed falling surface pressures.

Since Gerald was a shallow low-level circulation in an active monsoonal trough, its movement was erratic and difficult to forecast. During the period 040000Z to 071800Z, the primary numerical aid, the One-Way Interactive Tropical Cyclone Model (OTCM), was used by JTWC to forecast movement.

JTWC forecast Typhoon Gerald would slowly recurve to the east of Taiwan, however,

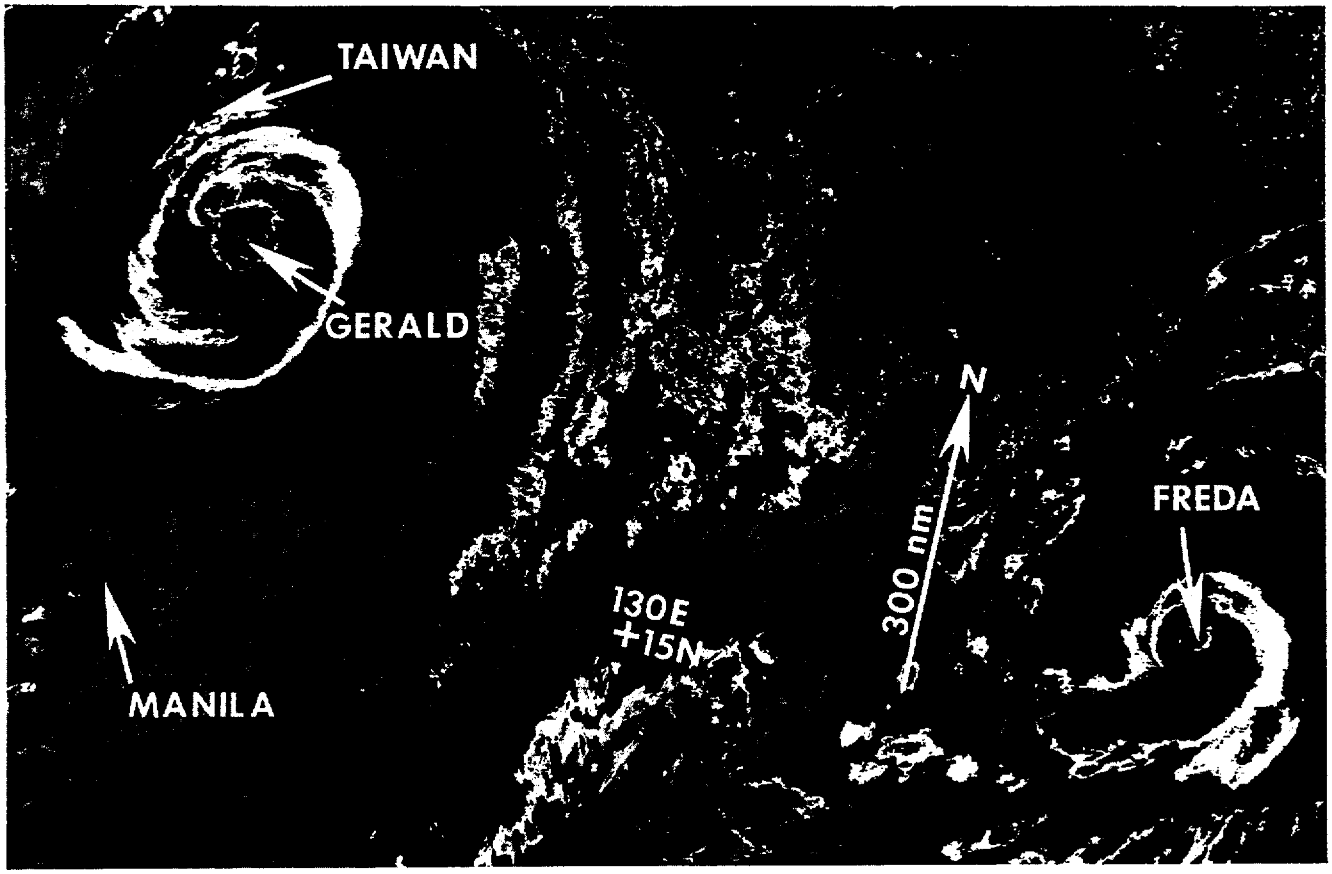


Figure 3-14-4. Typhoon Gerald at maximum intensity. The large eye is approximately 60 nm (111 km) in diameter. Prior to September, the 1987 season was characterized by an unusual number of 'midget' tropical cyclones. Typhoon Freda (13W), which also has an eye, is located approximately 1000 nm (1852 km) east-southeast of Gerald (082111Z September DMSP enhanced infrared imagery).

northwestward movement up the monsoonal trough began on the 7th, as did acceleration and intensification. The 081800Z warning signalled a major change in the expected movement of Typhoon Gerald. The forecast indicated Gerald would pass through the Luzon Strait and make landfall on the southeast coast of mainland China.

Typhoon Gerald, with a large classic eye 60 nm (111 km) in diameter, reached its maximum intensity of 105 kt (54 m/sec) at 081800Z (Figure 3-14-4). Later, Gerald skirted the southwest coast of Taiwan (Figure 3-14-5). The mountainous terrain reduced low-level inflow and Gerald began to weaken (Figure 3-14-6). Gerald continued to weaken over the Formosa Straits and made landfall on the China coast 50 nm (93 km) east-northeast of Amoy, a city about 245 nm (454 km) east-northeast of Hong Kong. The remnants of Gerald dissipated over land and were no longer apparent on either satellite imagery or synoptic data after 110000Z.

Typhoon Gerald caused extensive damage to Taiwan and China. In Taiwan, five people died and over $10 million in damage was caused by heavy rain and flooding. Up to 16 inches (41 cm) of rain was reported in parts of the Zhejiang Province, China (south of Beijing). Flooding inundated more than 1,950 square miles (505,440 hectares) of farmland, causing widespread damage to crops valued at $121 million. The Chinese death toll from Typhoon Gerald was 122.

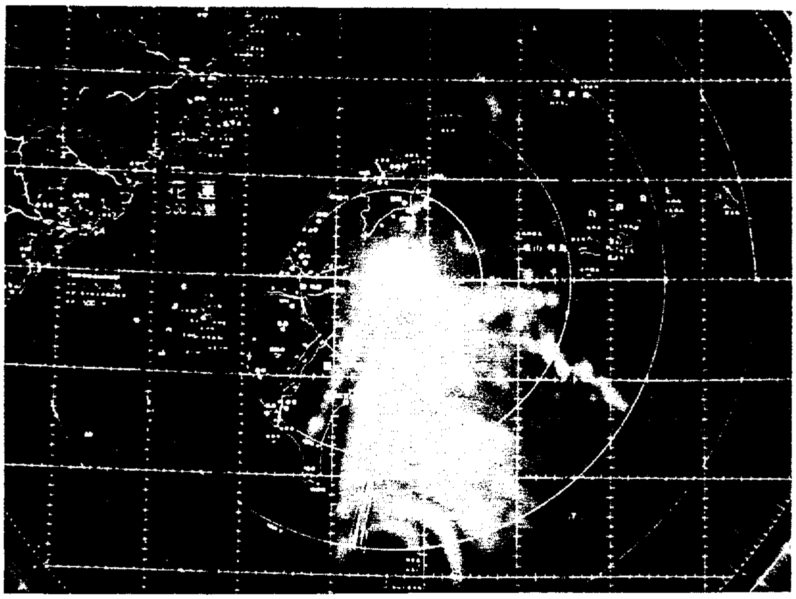


Figure 3-14-5. Radar presentation of the concentric rainbands of Typhoon Gerald as seen fron Hualien, Taiwan (WMO 46699) at 090200Z September (Photograph courtesy of Central Weather Bureau, Taipei, Taiwan).

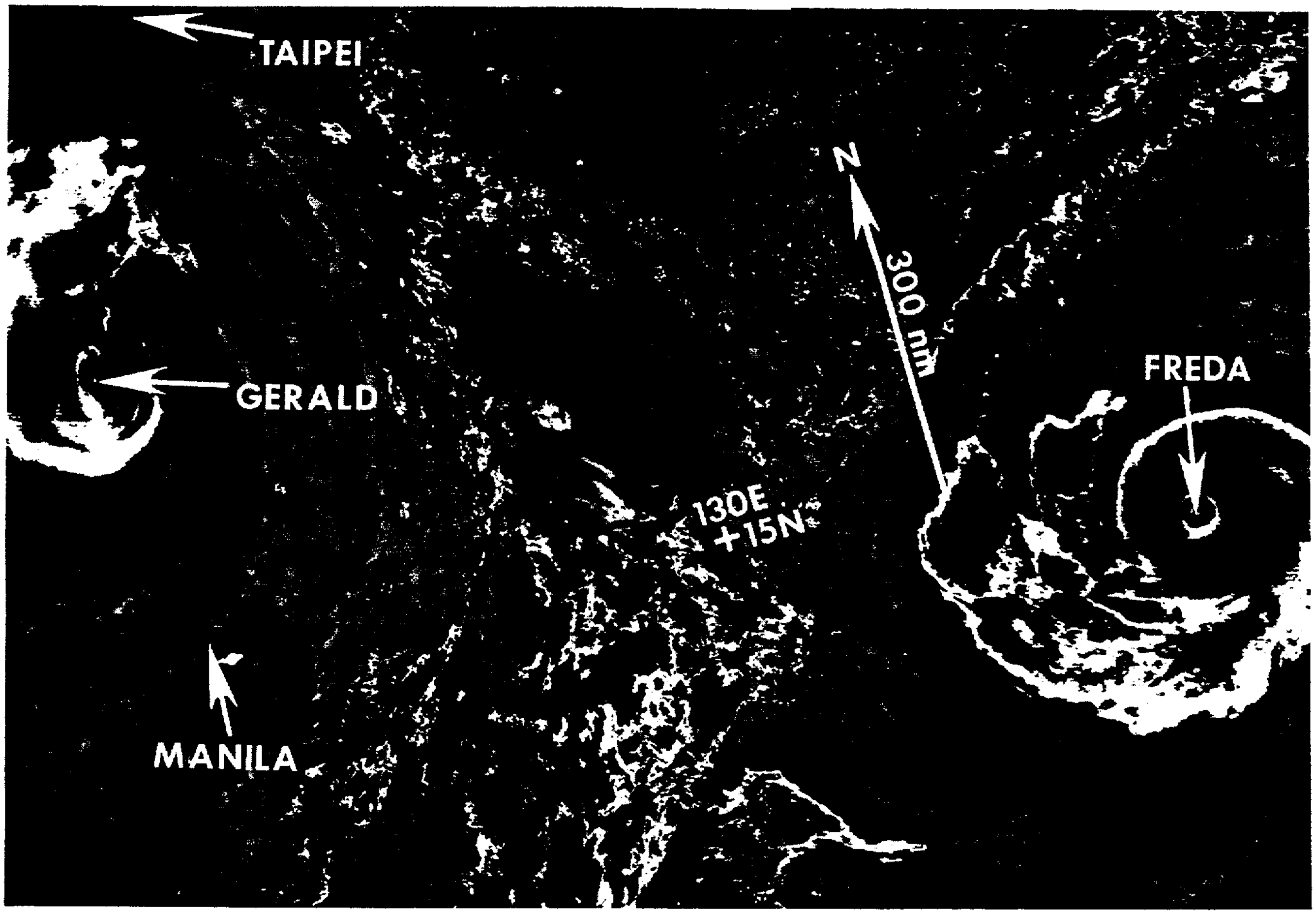
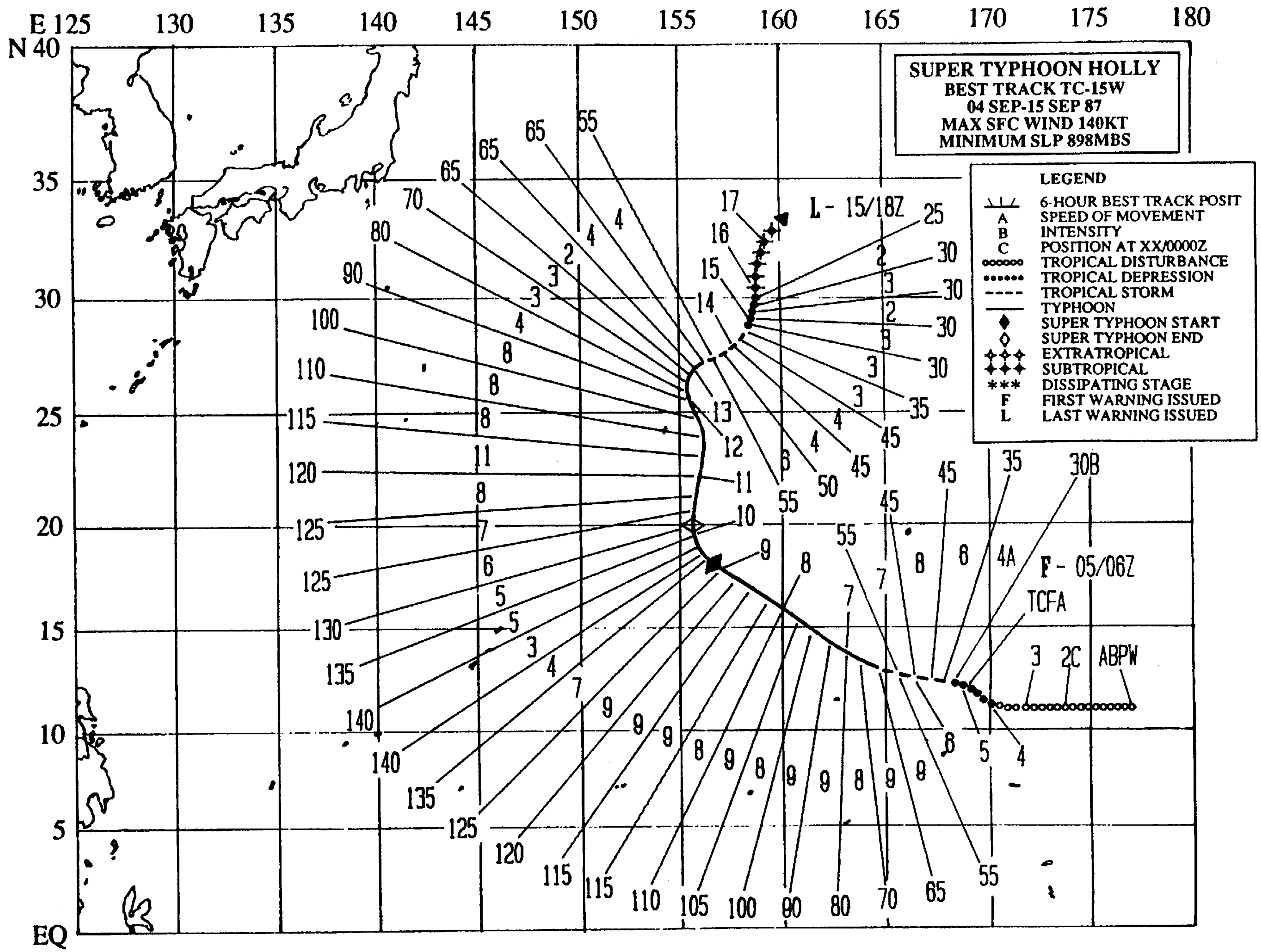


Figure 3-14-6. The effect of land interaction on Gerald's cloud pattern. This enhanced infrared image shows the distinct break in the central cloud mass to the north of the eye, which is related to lee-side subsidence over western Taiwan. This cloud-minimum area parallels the ridge line of mountainous central Taiwan (090956Z September DMSP infrared imagery).


SUPER TYPHOON HOLLY
BEST TRACK TC-15W
04 SEP-15 SEP 87
MAX SFC WIND 140KT
MINIMUM SLP 898MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 15/18Z
F - 05/06Z
TCFA
ABPW
E 125
130
135
140
145
150
155
160
165
170
175
180
N 40
35
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EQ

SUPER TYPHOON HOLLY (15W)

In early September the active monsoonal trough spawned a three tropical cyclone outbreak. Super Typhoon Holly was one of the three. Typhoons Freda (13W) and Gerald (14W) were first warned on at 041800Z September, with Holly following 12-hours later. As these three systems matured, the monsoon trough became displaced well to the north of its "normal" location (see Figures 3-15-1 and 3-15-2). In fact, by the 11th of September, Holly, Typhoon Freda (13W) and the remains of Typhoon Gerald (14W) were all north of 15 degrees North Latitude as an anticyclonic circulation developed in low-latitudes just north of the island of Pohnpei in the eastern Caroline Islands. This anomalous low-latitude high pressure suppressed additional cyclogenesis for the next four days (see Figure 3-15-3). Monsoonal troughing began to reappear on the 171200Z surface/gradient-level streamline analysis and was firmly re-established a day and a half later.

Holly began as a westward-moving area of persistent, but weakly organized, convection at the eastern end of the monsoon trough 560 nm (1037 km) east-northeast of Kwajalein and was first mentioned on the Significant Tropical Weather Advisory (ABPW PGTW) at 010600Z. As Holly developed over the next three days, satellite reconnaissance intensity estimates (Dvorak, 1984) of maximum sustained surface winds indicated an increase from 25 kt (13 m/sec) to 30 kt (15 m/sec). Vertical wind shear

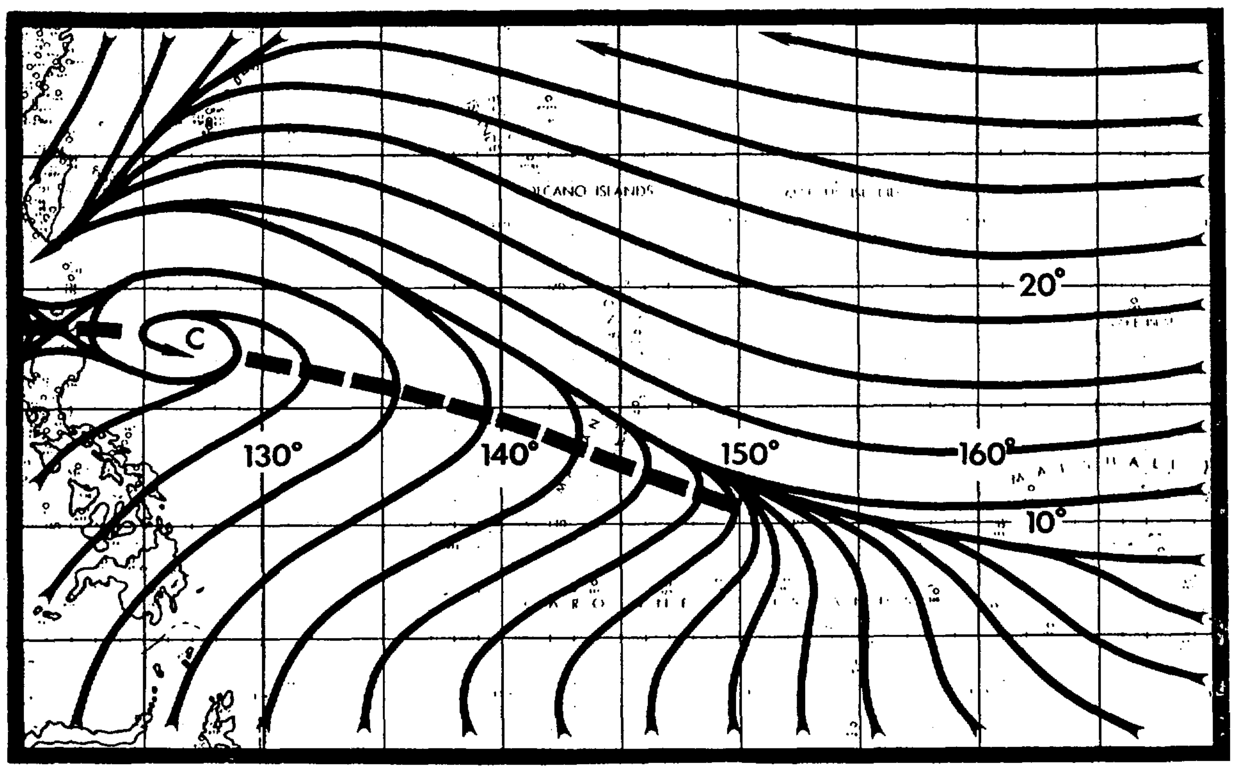


Figure 3-15-1. Gradient-level wind climatology for September (Sadler, et al, 1987).

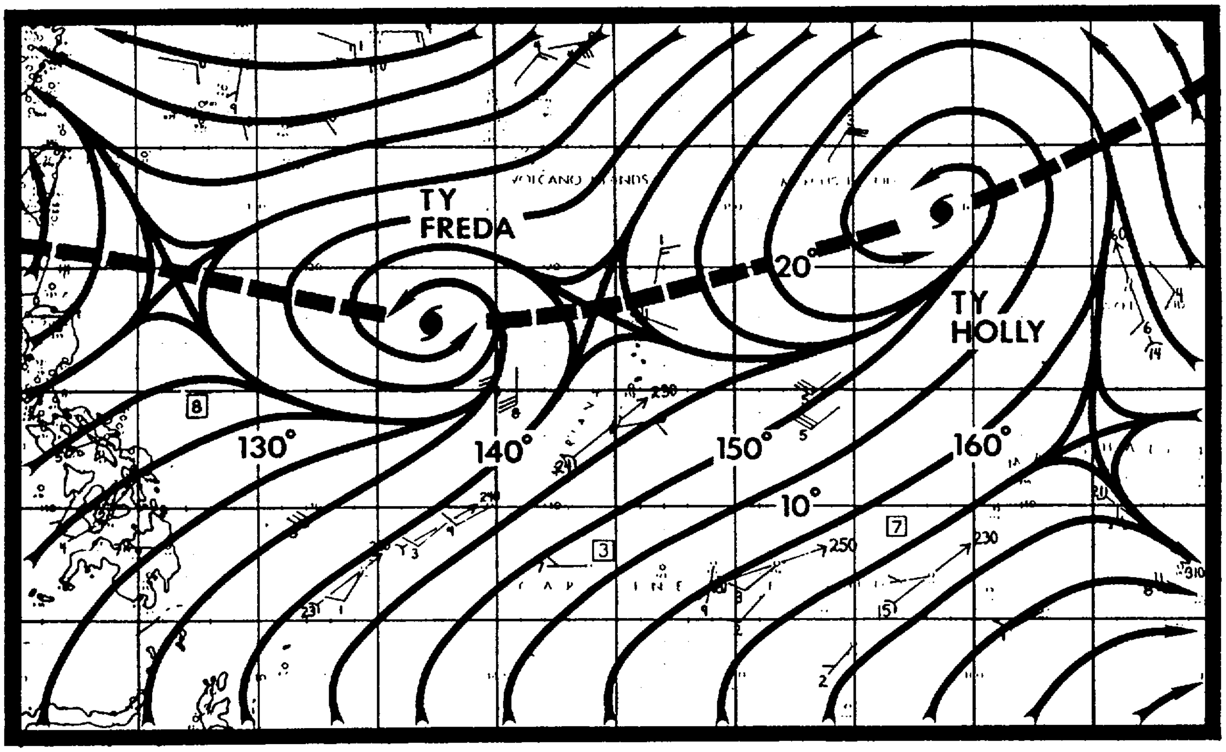


Figure 3-15-2. Low-level troughing is shown on this surface/gradient-level streamline analysis from 110000Z September well north of its climatological position (see Figure 3-15-1) due to the combined influences of Typhoons Freda (13W) and Holly, and the remains of Typhoon Gerald (14W).

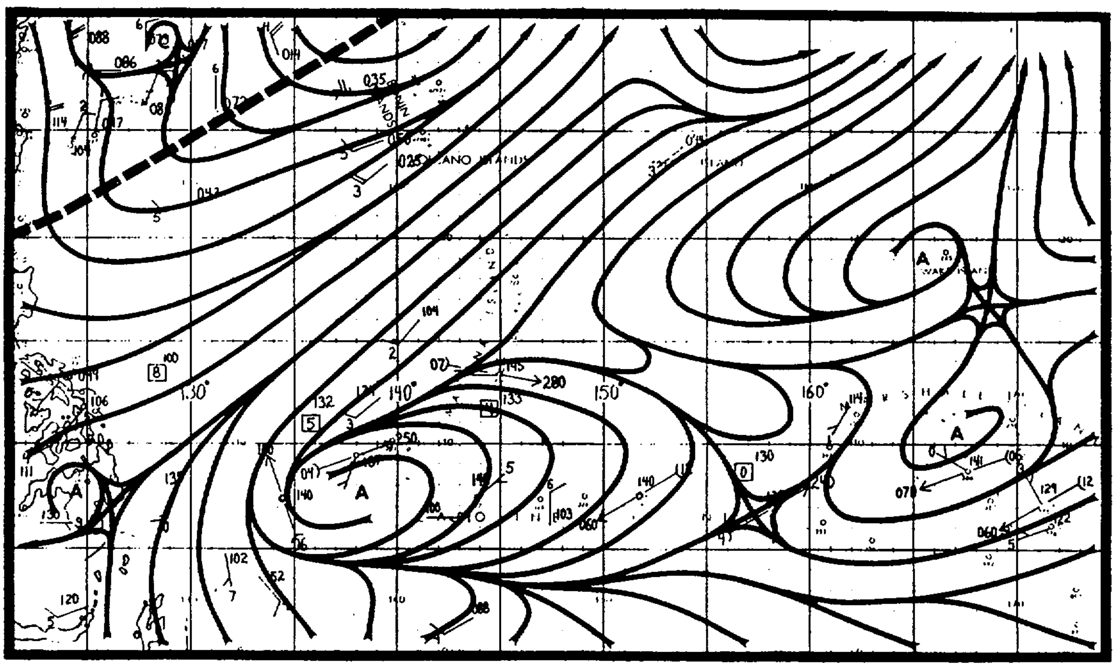


Figure 3-15-3. Ridging, shown as a band of anticyclones on this surface/gradient-level analysis for 161200Z September developed in latitudes normally expected to show monsoonal troughing. This appears to have been a key element in the suppression of further low-latitude tropical cyclone genesis through the 19th.

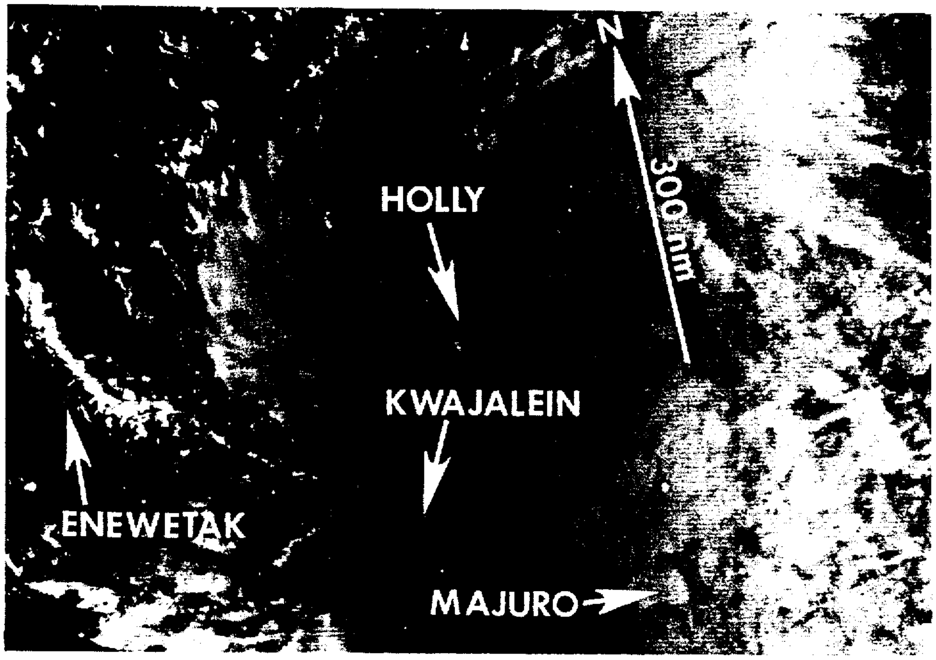


Figure 3-15-4. Holly near the time of its first warning (050721Z September DMSP visual imagery).

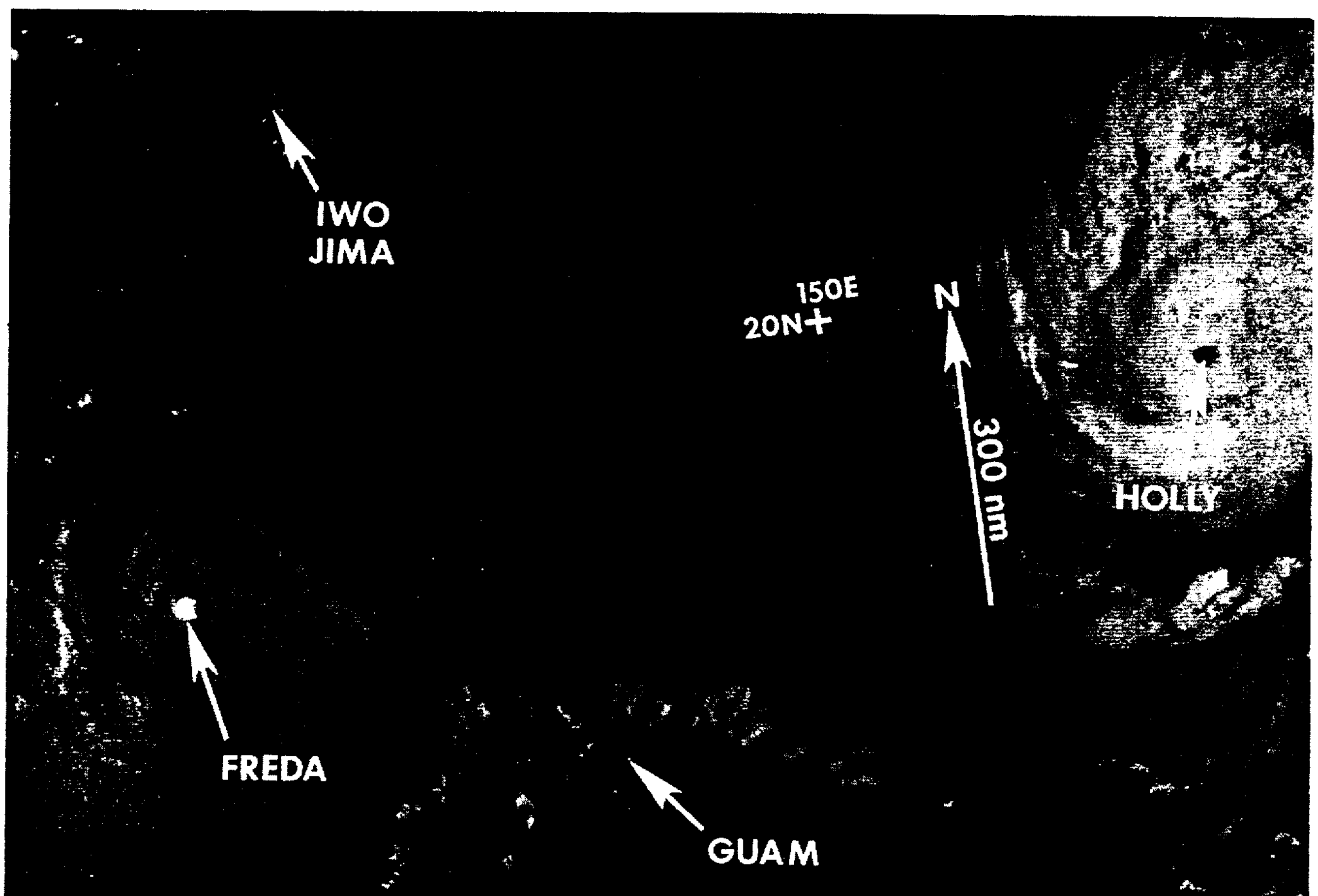


Figure 3-15-5. Super Typhoon Holly at peak intensity. Typhoon Freda (13W) appears to the left of Holly (091210Z September DMSP visual imagery).

over the system remained low (not more than 10 kt (5 m/sec)), favoring development. Surface/gradient-level streamline analysis at 040000Z showed moderate low-level cross-equatorial flow from the south into the disturbance. This was apparent from the southwesterly gradient-level winds at Truk (WMO 91334) and Pohnpei (WMO 91348) at 040000Z. Minimum sea-level pressures were 1006 mb in Holly with the mean environmental pressures near 1009 mb. This combination, together with indications that the deepest convection was consolidating about the low-level circulation center, supported the issuance of a Tropical Cyclone Formation Alert at 041930Z.

The first warning on Tropical Depression 15W followed at 050600Z. At that time, the maximum sustained surface winds were 30 kt (15 m/sec), with a forecast increase to 35 kt (18 m/sec) the next day. Satellite imagery on the 5th showed favorable upper-level outflow and a ragged central convective mass about 2 1/2 degrees in diameter (Figure 3-15-4). Associated convective bands southwest and east of the center implied a large-scale circulation and little competition for energy from Typhoon Freda (13W) to the west. As a consequence, Holly developed from 30 kt (15 m/sec) at the time of the first warning to 90 kt (46 m/sec) at the time of the ninth warning at 070600Z.

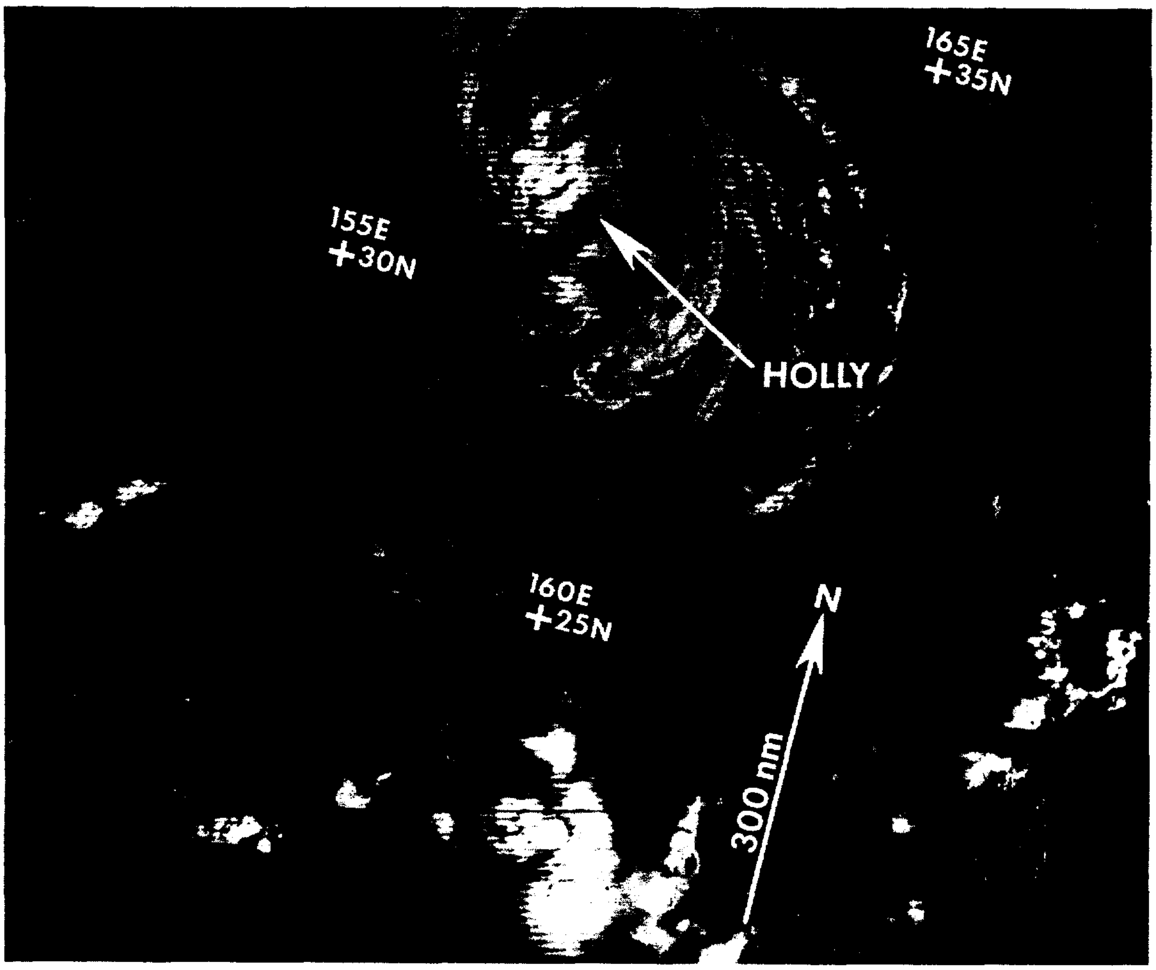
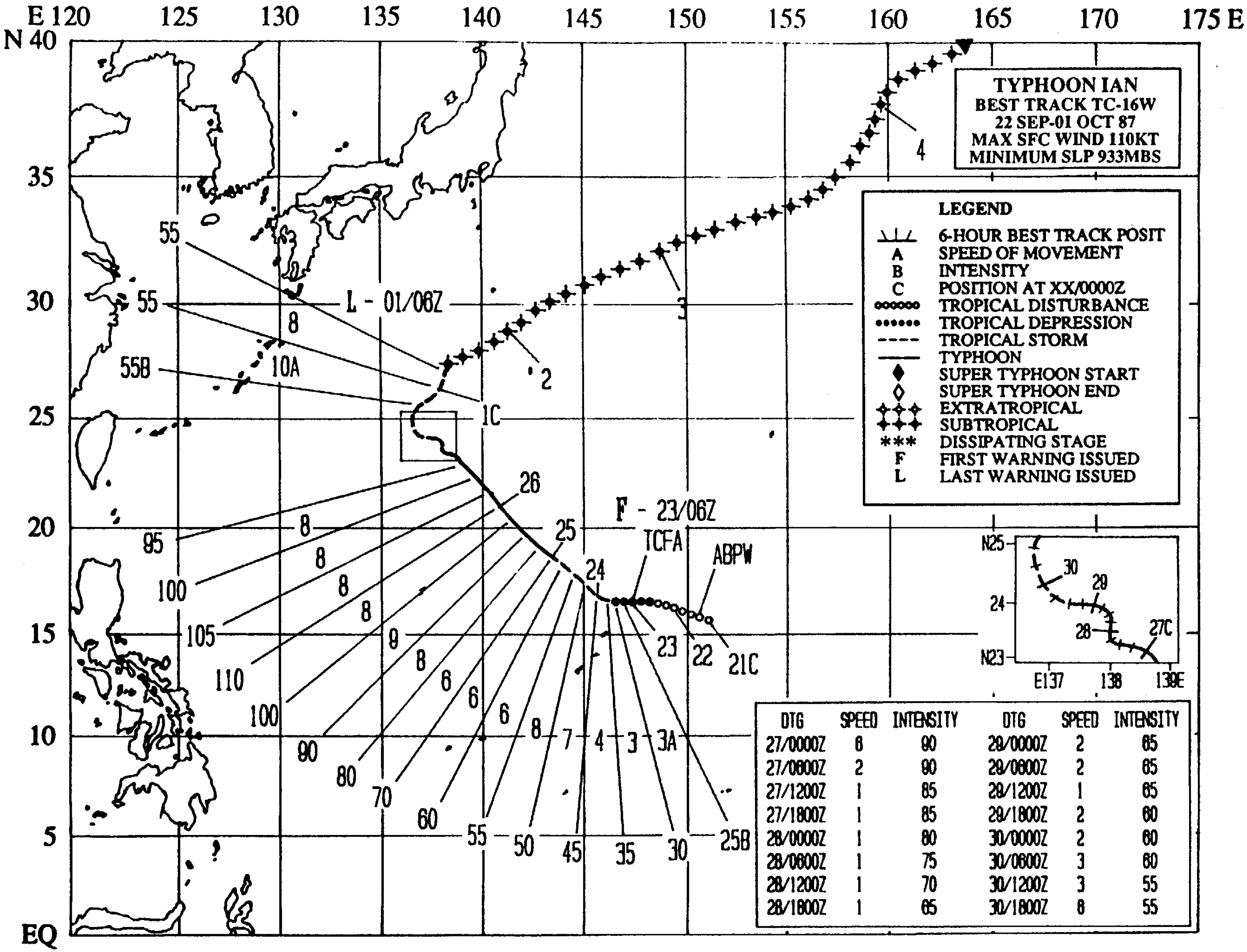


Figure 3-15-6. The subtropical remains of Holly (162227Z September DMSP visual imagery).

Holly's track abruptly changed from northwestward to northward at a position approximately 720 nm (1333 km) northeast of Guam. A maximum intensity of 140 kt (72 m/sec) was reached at 091200Z (Figure 3-15-5). Sparse upper-air and synoptic data did not clearly show a specific weakness in the subtropical ridge to the north of Holly. As a result, the early forecast tracks called for west-northwestward or westward movement. However, the relative movement and displacement of the monsoonal trough and the weakness of the subtropical ridge appear to have caused Holly's northward movement. (By the 10th, Typhoon Freda (13W) was about 950 nm (1759 km) to the west-southwest and drifting slowly west-northwestward. No binary interaction was apparent between Holly and Typhoon Freda (13W).) With no strong mid-latitude systems approaching to provide stronger westerly or southwesterly steering flow, Holly (along with Typhoon Freda (13W)) drifted slowly northward in the active monsoon trough and weakened. Holly acquired subtropical characteristics after 140300Z, and retained 45 kt (23 m/sec) maximum sustained surface winds. Its remnants could still be located on satellite imagery through the 17th (Figure 3-16-6), with the final satellite fix obtained at 170600Z. No reports of damage or loss of life were attributed to Holly during its lifetime.



DTG	SPEED	INTENSITY	DTG	SPEED	INTENSITY
27/0000Z	6	90	29/0000Z	2	65
27/0600Z	2	90	29/0600Z	2	65
27/1200Z	1	85	29/1200Z	1	65
27/1800Z	1	85	29/1800Z	2	60
28/0000Z	1	80	30/0000Z	2	60
28/0600Z	1	75	30/0600Z	3	60
28/1200Z	1	70	30/1200Z	3	55
28/1800Z	1	65	30/1800Z	6	55

TYPHOON IAN (16W)

Typhoon Ian was the fourth of seven tropical cyclones to occur in the western North Pacific during September. Ian developed into a significant tropical cyclone six days after the second three-storm warning situation of the year involving Typhoons Freda (13W), Gerald (14W) and Super Typhoon Holly (15W) had ended on September 17th. Thirty-six hours after the first warning on Ian, it was joined by Tropical Depression 17W, which brought to seven the number of periods during 1987 that JTWC was warning on at least two systems at the same time. Even though, Tropical Depression 17W was a very short-lived system, Hurricane Peke (02C), which crossed the dateline (becoming Typhoon Peke (02C)), and Tropical Storm June (18W) soon took its place. This gave rise to the third three-storm warning situation of the year and the second to occur during September.

Forecasts verified extremely well on Typhoon Ian. The forecast track error statistics for all three verification times (i.e., 24-, 48- and 72-hours) were significantly less than the five-year average (see Chapter V, Tables 5-1A through 5-2B), though the 72-hour forecast error of 344 nm (637 km) exceeded the 1987 average. The reason for the poor 72-hour forecast errors was the unexpected slower movement of Ian between 270600Z and 290000Z when the system became nearly quasi-stationary while tracking generally toward the northwest. If this abnormal behavior had not occurred, JTWC's statistics on Ian would have been outstanding.

Ian began as a broad, poorly organized tropical disturbance 330 nm (611 km) to the east-northeast of Guam. Satellite analysts from Detachment 1, 1st Weather Wing (Det 1, 1WW) alerted the Typhoon Duty Officer to the presence of a persistent area of convection showing improved upper-level outflow. This was in the region where the monsoonal trough was attempting to become re-established after being disrupted by the previous three-storm situation. On 21 September at 0600Z, JTWC added the disturbance to its Significant Tropical Weather Advisory (ABPW PGTW) and listed its potential for development as poor due to the relatively high minimum sea-level pressures (MSLPs) evident in the trough at that time. Within 24-hours, the MSLPs decreased by 2 mb and the wind speeds increased another 5 kt (3 m/sec) to 25 kt (13 m/sec) (see Figure 3-16-1).

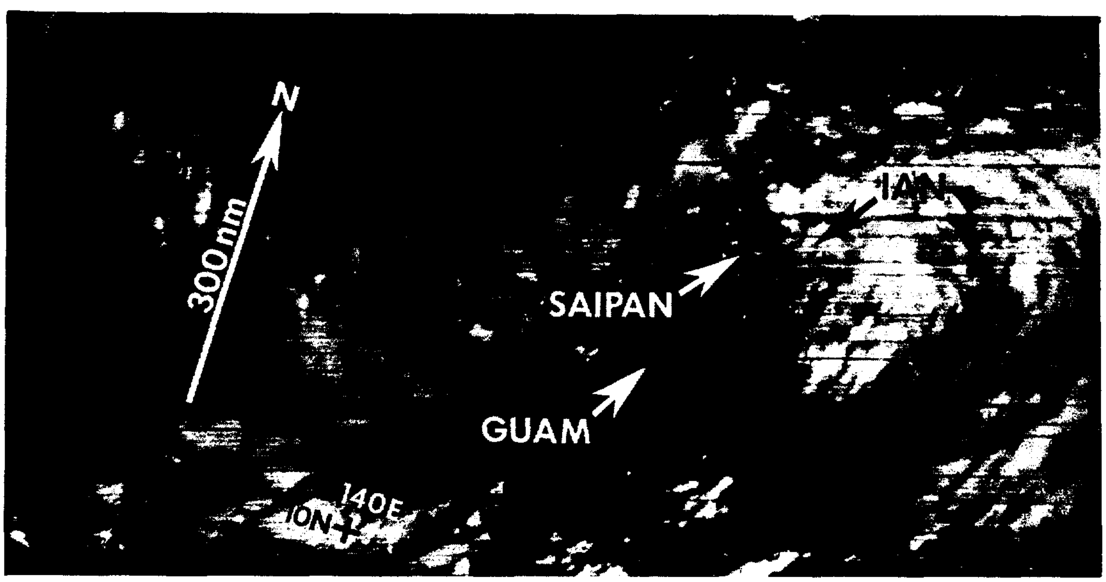


Figure 3-16-1. Ian, as a tropical disturbance with 25 kt (13 m/sec) maximum sustained winds at the surface (220007Z September DMSP visual imagery).

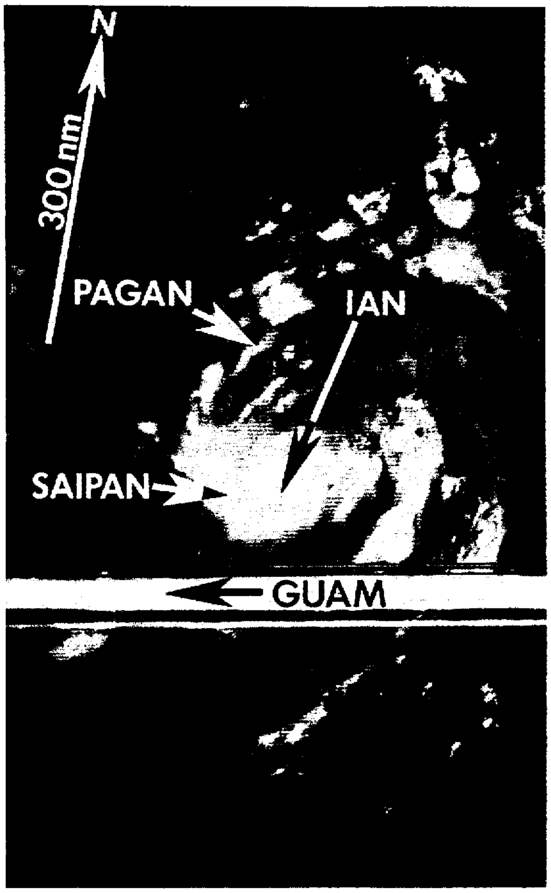


Figure 3-16-2. Curvature is evident in the convective cloud lines just prior to JTWC issuing a Tropical Cyclone Formation Alert at 230130Z (222346Z September DMSP visual imagery).

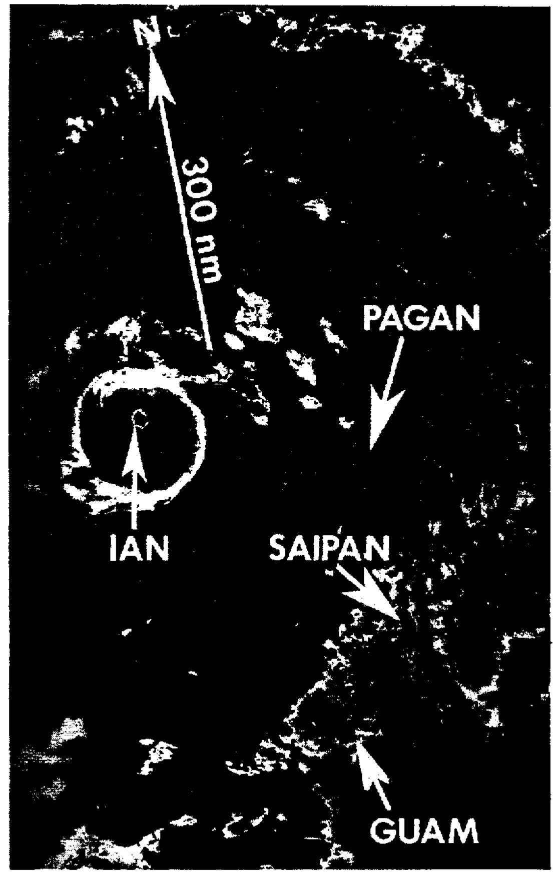


Figure 3-16-3. Typhoon Ian approximately 12-hours before reaching its maximum intensity of 110 kt (57 m/sec). Note the small circular eye and compact central dense overcast (251146Z September DMSP enhanced infrared imagery).

Ian continued its slow-paced development. Early on the 23rd, satellite imagery (see Figure 3-16-2) showed further intensification had taken place. Curvature became evident in the low-level cloud lines. Satellite intensity analysis (Dvorak, 1984) of imagery at 222346Z estimated 30 kt (15 m/sec) winds at the surface associated with this disturbance. JTWC promptly issued a Tropical Cyclone Formation Alert at 230130Z for the Mariana Islands north of Guam.

JTWC issued the first warning on Ian (as Tropical Depression 16W) at 230600Z, with an intensity of 25 kt (13 m/sec) and gusts to 35 kt (18 m/sec), based on spiral bands of convection which became visible on visual and infrared satellite imagery. The system was upgraded to Tropical Storm Ian (16W) on the third warning (231800Z) as it progressed slowly westward into an area of low vertical wind shear.

At about that time, Ian began to develop at slightly greater than the normal Dvorak rate of one "T-number" per day. Wind speeds increased from 35 kt (18 m/sec) at 231800Z to 60 kt (31 m/sec) at 241800Z. Midway through this period, Ian turned from its westward course and began to move toward the northwest. Five radar fixes were obtained from Andersen Air

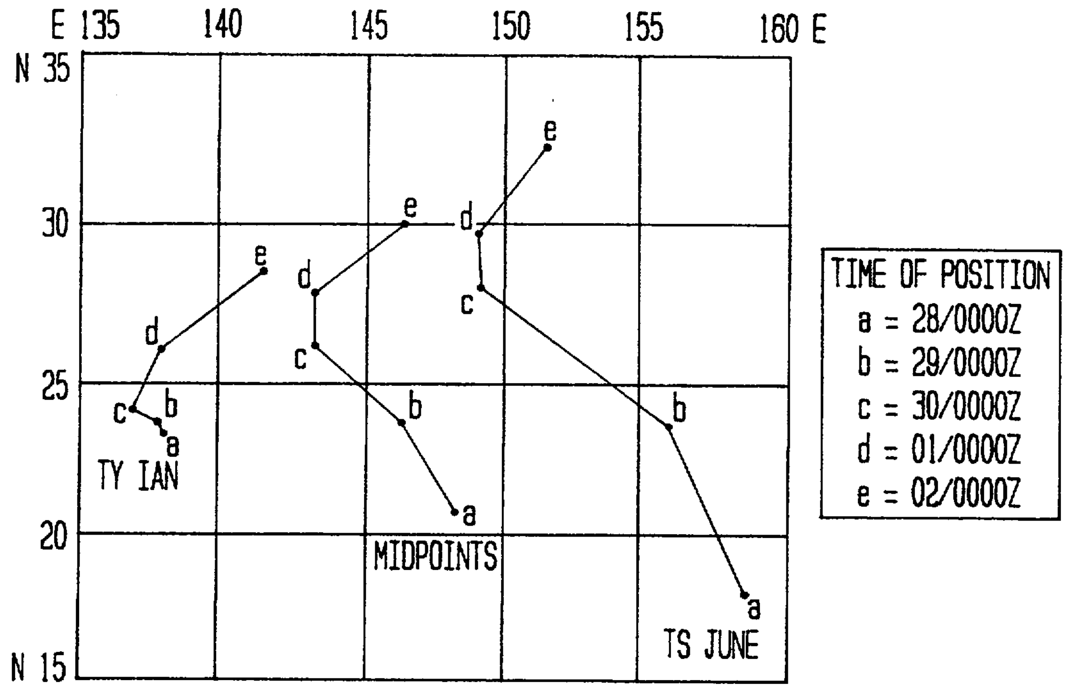


Figure 3-16-4. Plot of the slight binary interaction between Ian and June (18W) showing their individual tracks and the path of the midpoints.

Force Base on Guam during this same time period. The center positions were based on the convective banding features. No eye feature was apparent on radar for any of the fixes.

Between 241800Z and 250000Z, Ian reached typhoon intensity as it moved steadily toward the northwest at 7 kt (13 km/hr). It intensified at a rate of 10 kt (5 m/sec) per six-hour interval (i.e., between warning times) from 241800Z through 260000Z (Figure 3-16-3). Note the small circular eye and the compact nature of the deepest convection. Ian reached its maximum intensity of 110 kt (57 m/sec) at 260000Z. It was during this time of steady intensification that Tropical Depression 17W developed and then dissipated to the east of Ian. No binary interaction was apparent between them. A steady, slow decline followed. Twenty-four hours after Tropical Depression 17W had dissipated Ian slowed dramatically in forward speed as it approached a mid-latitude front lying just to the east of the Ryukyu Islands. Ian inched slowly northward between the times of 270600Z and 290000Z at a rate of less than 2 kt (4 km/hr). Its deep central convection decreased significantly. The movement of a mid-latitude shortwave north of Ian appeared to

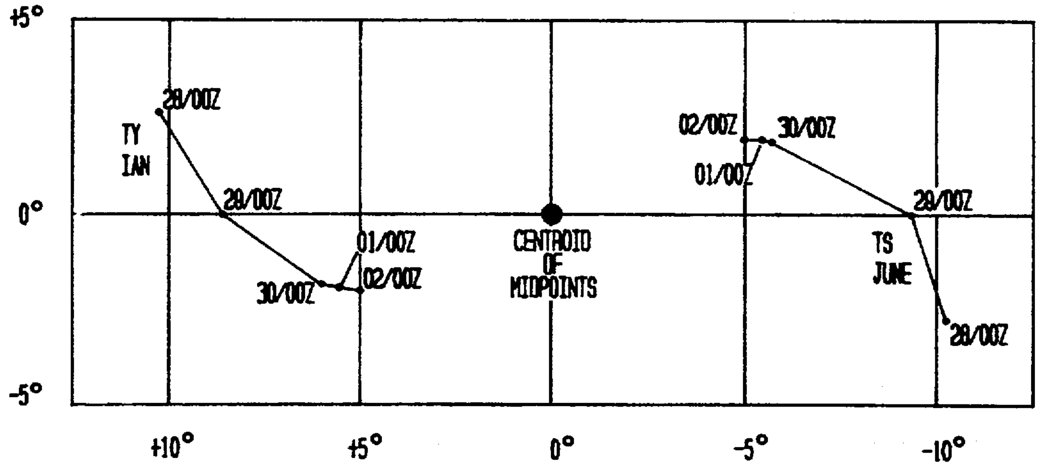


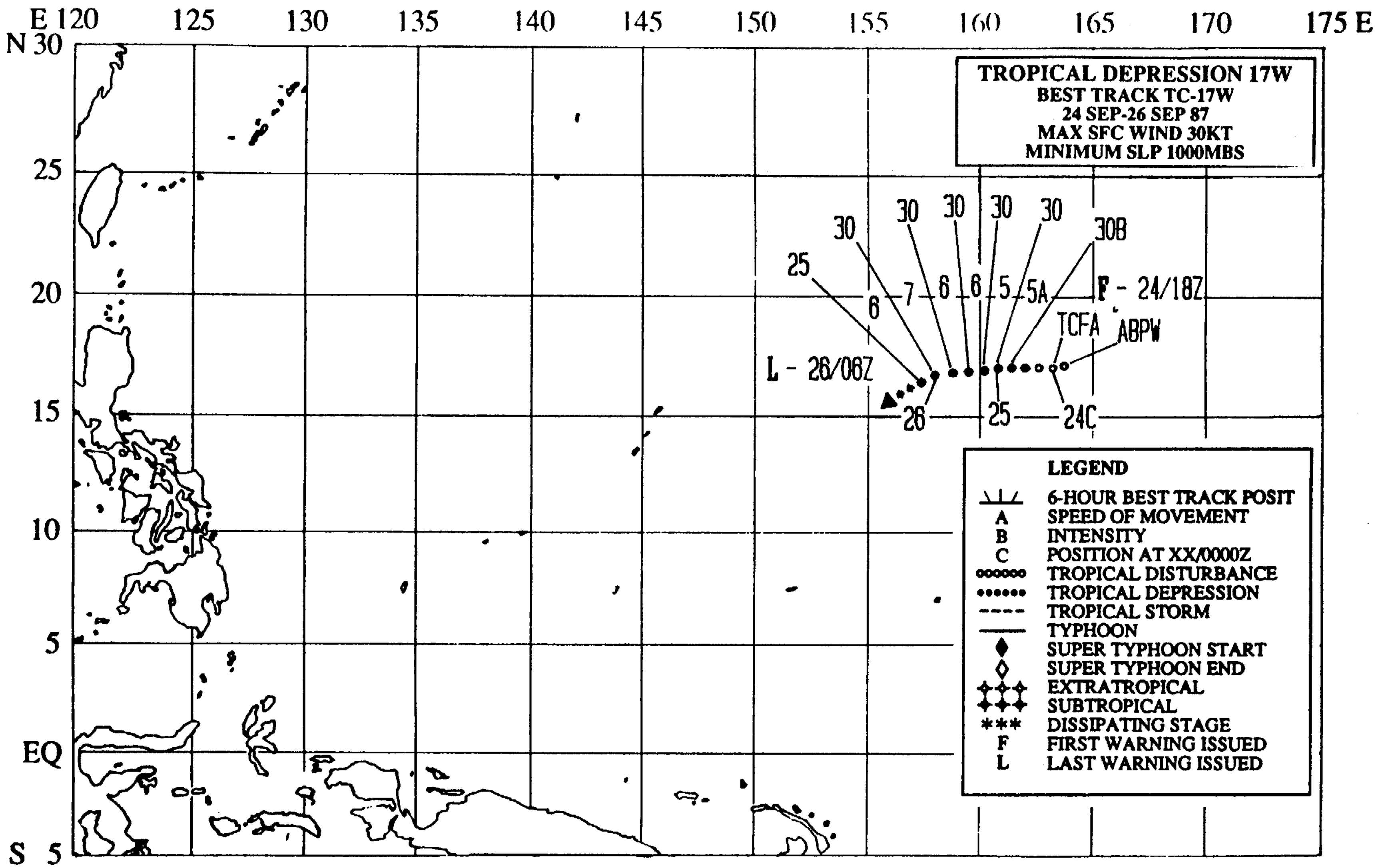
Figure 3-16-5. Plot of the center-relative movement about the midpoint centroid.

have suppressed it. Once this shortwave moved off toward the east on the 29th, Ian's upper-level outflow became aligned with the jet stream (which was above the lower level front) and the system began recurving south of Japan.

Meanwhile Tropical Storm June (18W), which began its development on the 28th, was moving rapidly northwestward at 18 to 20 kt (33 to 37 km/hr). Ian and June (18W) were close to one another at this stage (within 400 nm (741 km)) and eventually underwent a slight binary interaction between 300000Z September and 020000Z October. In Figure 3-16-4, the midway point is plotted for the times the two systems coexisted. Figure 3-16-5 shows a plot of the relative movement of each system with respect to the centroid position. As Ian and June (18W) moved northeastward and dissipated, the separation between their tracks decreased.

Ian continued to slowly weaken as this interaction took place, however JTWC forecasters and the Det 1, 1WW satellite analysts misread the changes to Ian on satellite imagery. Dvorak analysis at 010600Z October estimated Ian's intensity at 30 kt (15 m/sec), which supported a final warning and a downgrade to tropical depression intensity. Post-analysis indicates that Ian most probably transitioned to a subtropical system (rather than extratropical since the subtropical ridge was located to the north of Ian) and still had 55 kt (28 m/sec) winds at the time of the final warning.

The remnants of Ian continued to move northeastward after it transitioned to subtropical and finally dissipated 1200 nm (2222 km) to the east of Japan on the 4th of October. No damage or deaths were attributed to Ian.


TROPICAL DEPRESSION 17W
BEST TRACK TC-17W
24 SEP-26 SEP 87
MAX SFC WIND 30KT
MINIMUM SLP 1000MBS
E 120
125
130
135
140
145
150
155
160
165
170
175 E
N 30
25
20
15
10
5
EQ
S 5
25
30
30
30
30
30
30B
6
7
6
6
5
5A
F - 24/18Z
TCFA
ABPW
L - 26/06Z
26
25
24C
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION 17W

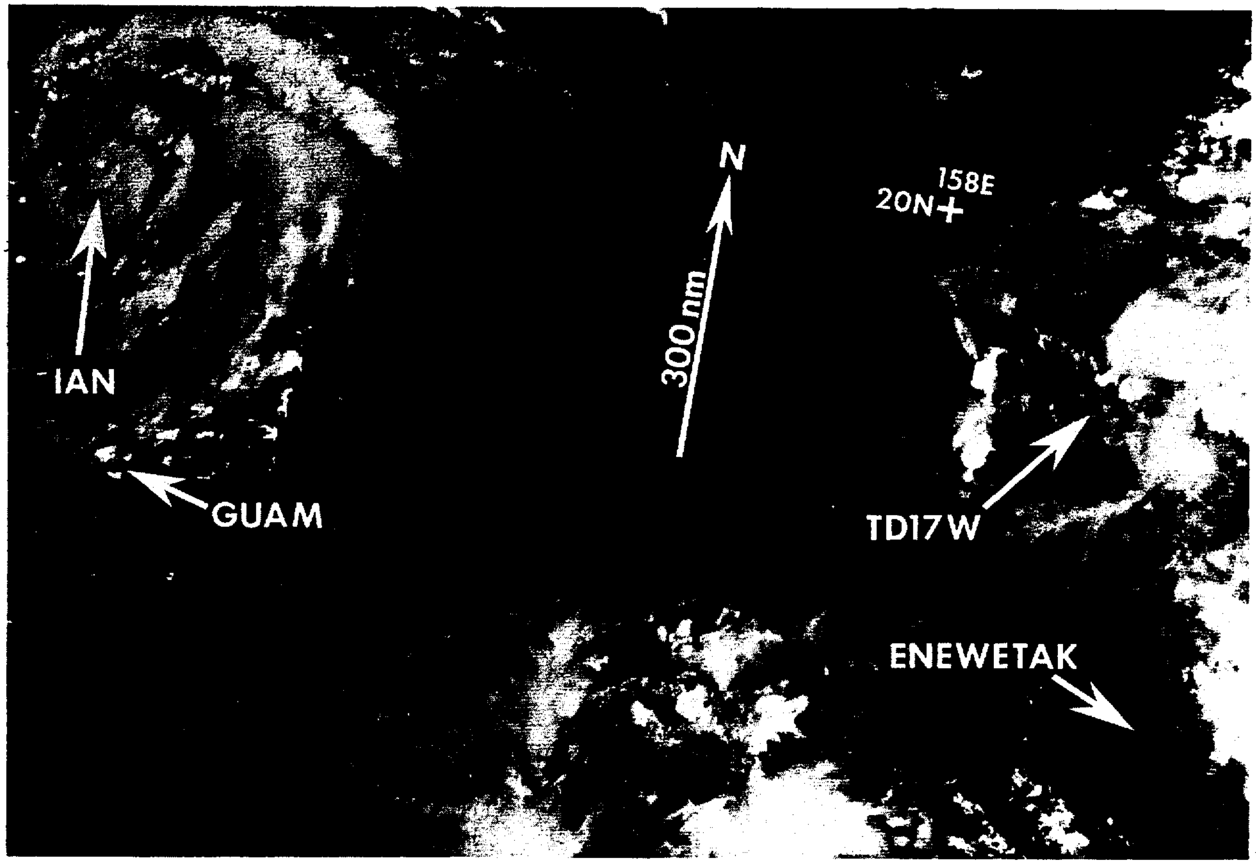
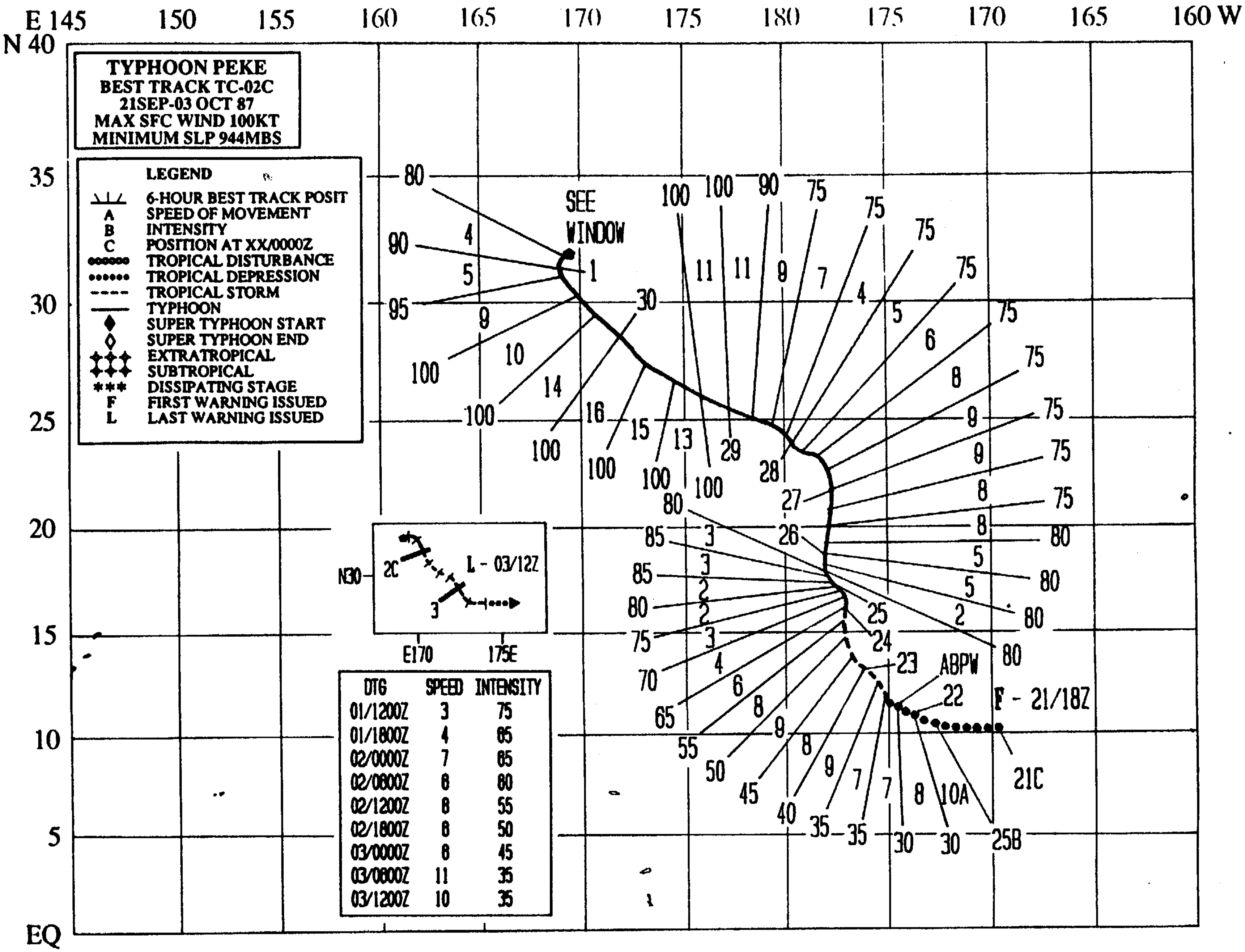


Figure 3-17-1. Tropical Depression 17W slowly developed from a tropical disturbance 250 nm (463 km) north of the Marshall Islands during the same period JTWC was warning on Typhoon Ian (16W). It was first detected on satellite imagery on the 23rd of September and mentioned on the Significant Tropical Weather Advisory (ABPW PGTW) as a new suspect area at 0600Z. JTWC issued a Tropical Cyclone Formation Alert nearly 24-hours later at 240330Z when this system displayed increased convective organization. Maximum sustained surface winds, at that time, were estimated at 15 to 25 kt (8 to 13 m/sec). The first warning on Tropical Depression 17W was issued at 241800Z based on satellite intensity estimate (Dvorak, 1984) of 35 kt (18 m/sec) winds at the surface. A well-established mid-level ridge was located to the northeast of Tropical Depression 17W. At the same time, an eastward-progressing, mid-latitude trough to the north was beginning to influence the system. This trough continued to suppress Tropical Depression 17W's development even after it had passed to the northeast of the disturbance. Concurrently, Typhoon Ian's (16W) upper-level outflow (at the left of the image) restricted Tropical Depression 17W's outflow in the northwest quadrant. This combination of factors appears to have stopped further intensification and induced dissipation over water. The last warning was issued on the 26th of September at 0600Z. The satellite image above shows Tropical Depression 17W shortly before the second warning was issued, while it was at its maximum intensity of 30 kt (15 m/sec) and 960 nm (1778 km) east-southeast of Typhoon Ian (16W). A partially exposed low-level circulation is visible slightly west of the heaviest convection (242305Z September DMSP visual imagery).



DTG	SPEED	INTENSITY
01/1200Z	3	75
01/1800Z	4	65
02/0000Z	7	65
02/0600Z	6	60
02/1200Z	8	55
02/1800Z	8	50
03/0000Z	8	45
03/0600Z	11	35
03/1200Z	10	35

TYPHOON PEKE (02C)

Typhoon Peke (02C) was the first hurricane during the past twenty years (since Typhoon Sara (28) in September 1967) to form in the central North Pacific and cross the dateline. Peke was the only significant tropical cyclone to cross the dateline north of the equator this year. The first twenty-five advisories were issued by the Central Pacific Hurricane Center (CPHC) in Honolulu, Hawaii (the Naval Western Oceanography Center at Pearl Harbor, Hawaii issued the corresponding warnings for the Department of Defense customers). The final twenty-three warnings were issued by JTWC.

Peke began as a broad area of convection about 480 nm (889 km) to the south-southeast of Johnston Island in the west central North Pacific on the 20th of September. The system tracked toward the west and increased in convection and organization over the next 24-hours. The upper-level outflow was initially restricted by an upper-level trough to the north of the system. The first advisory on Tropical Depression 02C was issued by CPHC at 211800Z. Satellite imagery indicated a low-level cyclonic circulation with spiral banding. This developed after the tropical cyclone had moved toward the west past the restricting influence of the upper-level trough to the north.

Over the next 18-hours, the amount of convection continued to increase. Upper-level outflow was unrestricted to the south and was becoming less restricted to the north, prompting the upgrade to Tropical Storm Peke (02C). During this time, Peke changed its track from westward to northwestward in response to a mid-level weakness in the subtropical ridge. It continued to intensify at a normal rate (Dvorak, 1984) and began to track more toward the north. CPHC upgraded the system to Hurricane Peke (02C) at 231800Z based on the formation of a banding-type eye, but Dvorak intensity post-analysis indicated that the system most probably did not reach hurricane intensity for another 6- to 12-hours. Peke continued to intensify and reached a first peak, of 85 kt (44 m/sec), at 250000Z.

Peke continued moving northward until 270600Z. After which time, it tracked toward the west-northwest in response to the strong mid-level flow around the subtropical ridge lying to the north of the system. CPHC issued their last advisory on Hurricane Peke (02C) at 271800Z September. It was approximately 30 nm (56 km) to the east of the dateline when JTWC issued its first warning (warning number 26) and redesignated the system as Typhoon Peke (02C) at 280000Z. Peke crossed the dateline at 280600Z. After having maintained a steady 75 kt (39 m/sec) intensity for over 36-hours, it began to re-intensify. Peke reached its second peak intensity (of 100 kt (51 m/sec)) between 290600Z and 291200Z, as upper-level outflow to the north improved.

Shortly afterward, JTWC was issuing warnings on three western North Pacific systems. Typhoon Ian (16W) was over 2000 nm (3704 km) to the west, and having little effect directly on Peke. About 1000 nm (1852 km) to the west of Peke, Tropical Storm June (18W) was beginning to organize (Figure 3-02C-1). Peke, together with Typhoon Ian (16W) and Tropical Storm June (18W), modified the environment and forced the subtropical ridge axis even further north to beyond 35 degrees North Latitude.

Earlier, as Peke crossed the dateline, it accelerated over a 48-hour period from near 7 kt (13 km/hr) forward speed to about 16 kt (30 km/hr). At that time, Peke began to entrain drier air into its central region. Satellite imagery at 291800Z indicated that a banding eye was present instead of an eye within a central dense overcast. Peke maintained its intensity and was still at 100 kt (51 m/sec) at 301200Z, when the system began to decelerate. At that time, recurvature was forecast along with rapid weakening due to strong westerly flow aloft. Peke became nearly quasi-stationary at 010600Z October, prior to recurvature. Within six hours, Peke was recurving toward the north-northeast and had steadily weakened from 100 kt (51 m/sec) at 301200Z September to 75 kt (39 m/sec) at 011200Z October. Over

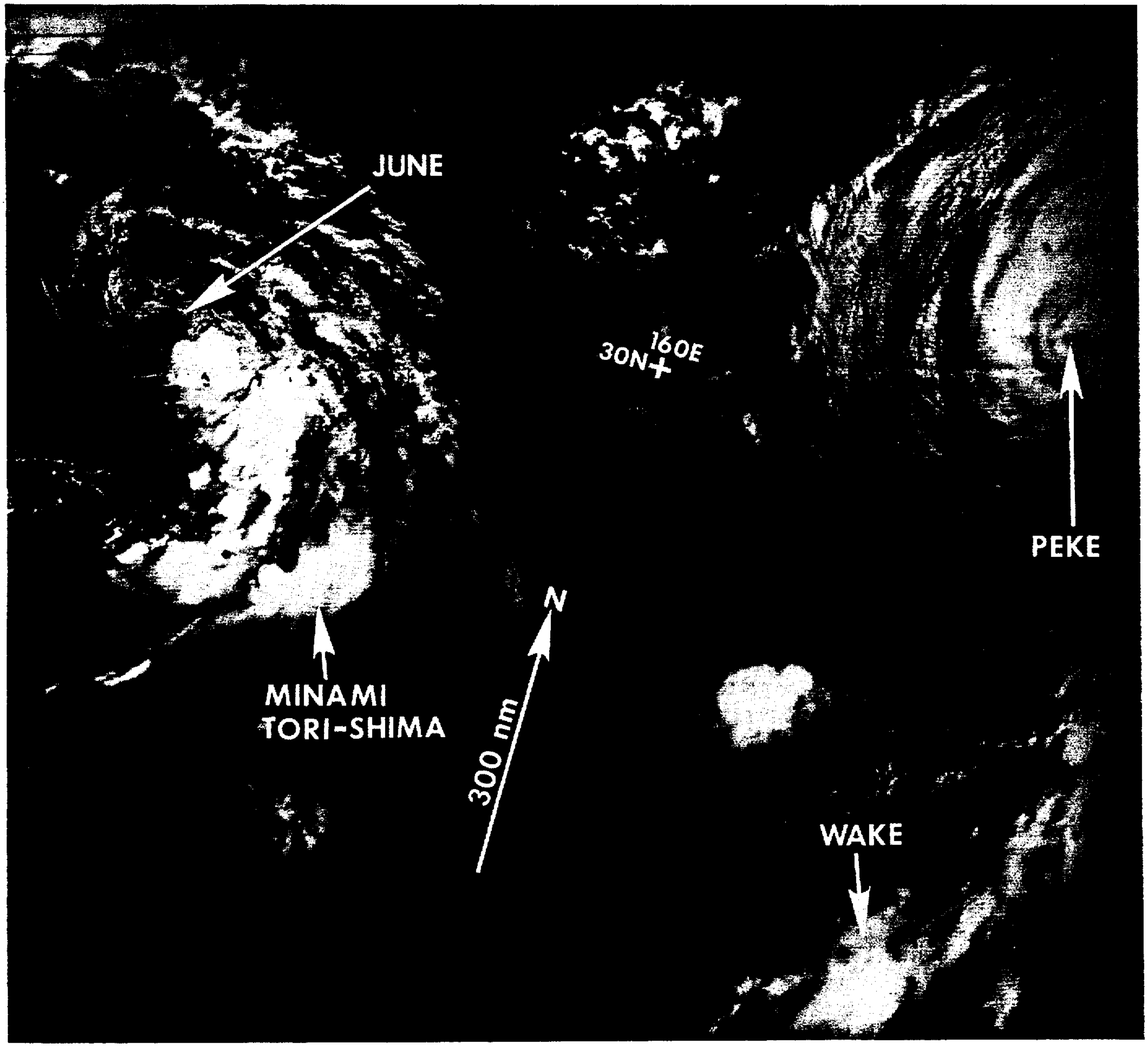
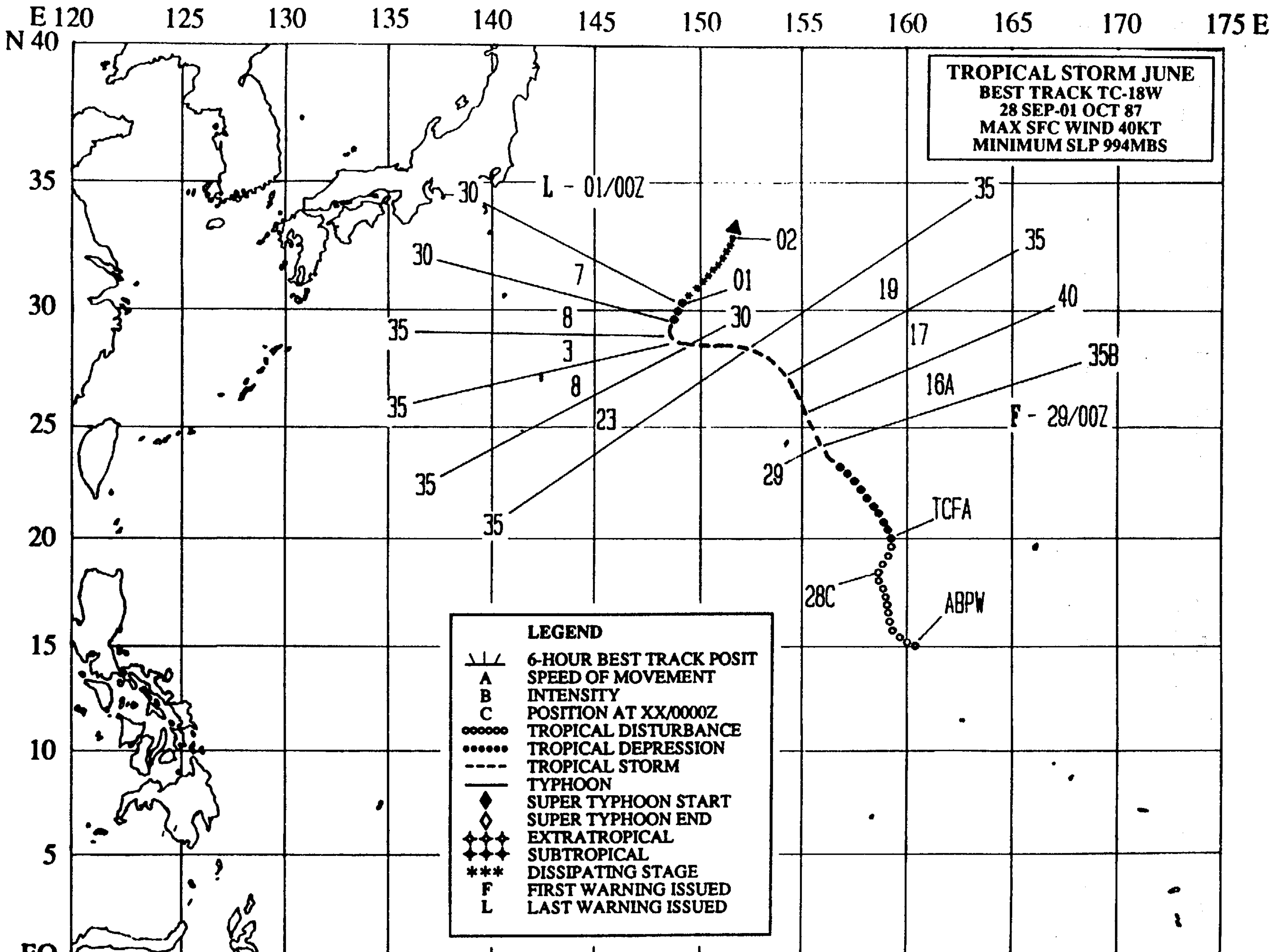


Figure 3-02C-1. Typhoon Peke (02C) with Tropical Storm June (18W) to the west (302243Z September DMSP infrared imagery).

the next day, Peke weakened even more, to 55 kt (28 m/sec), but instead of tracking toward the north-northeast, the low-level drifted toward the southeast, while the upper-level tracked toward the south-southeast in response to weak steering flow and increasing vertical wind shear. The last warning on Tropical Depression 02C was issued by JTWC at 031200Z. The remnants of Peke moved erratically over the next three and one half days in response to weak steering flow, first tracking toward the east, then toward the northwest and finally back toward the southeast until it could no longer be identified on satellite imagery.


TROPICAL STORM JUNE
BEST TRACK TC-18W
28 SEP-01 OCT 87
MAX SFC WIND 40KT
MINIMUM SLP 994MBS
L - 01/00Z
F - 29/00Z
TCFA
ABPW
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM JUNE (18W)

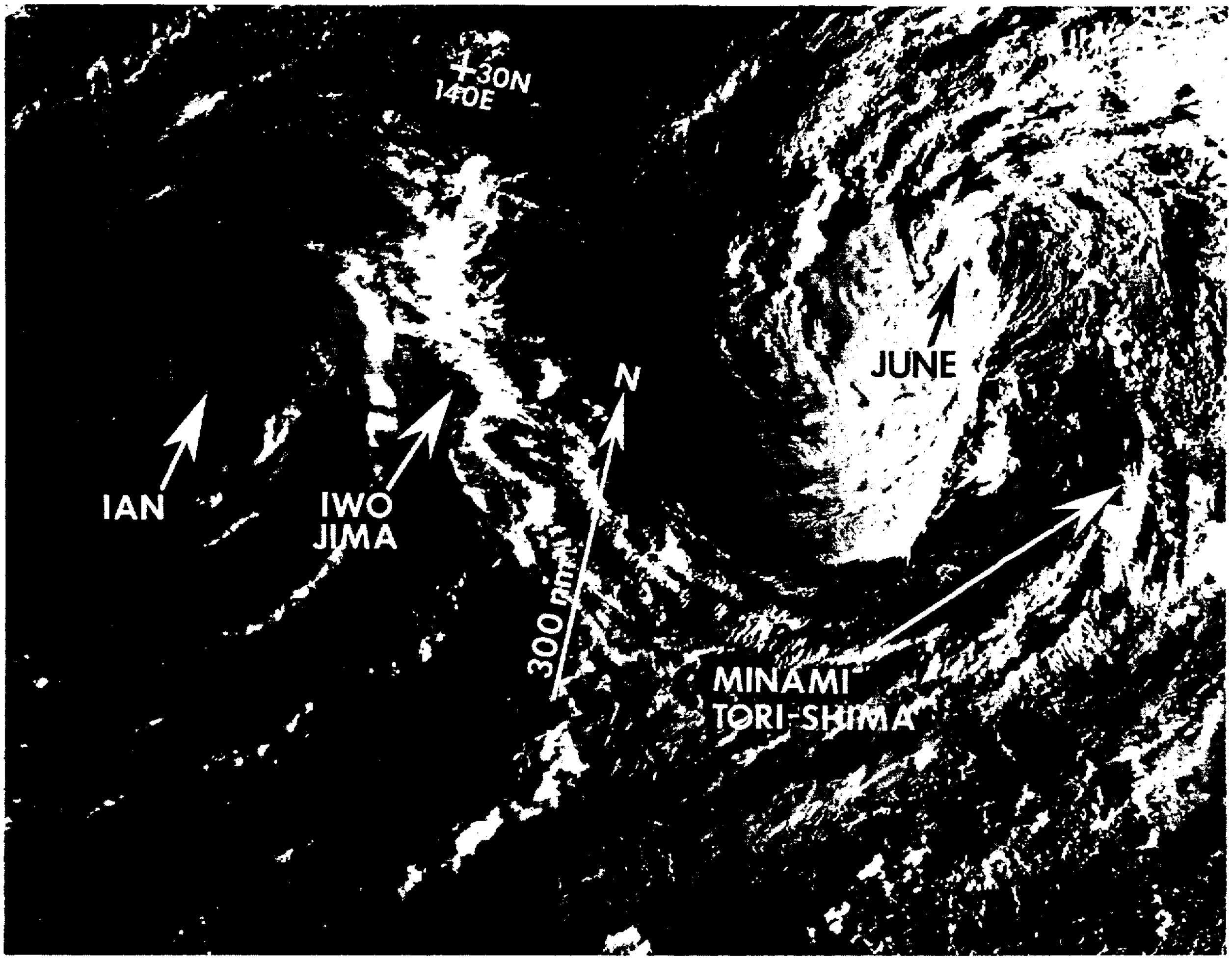
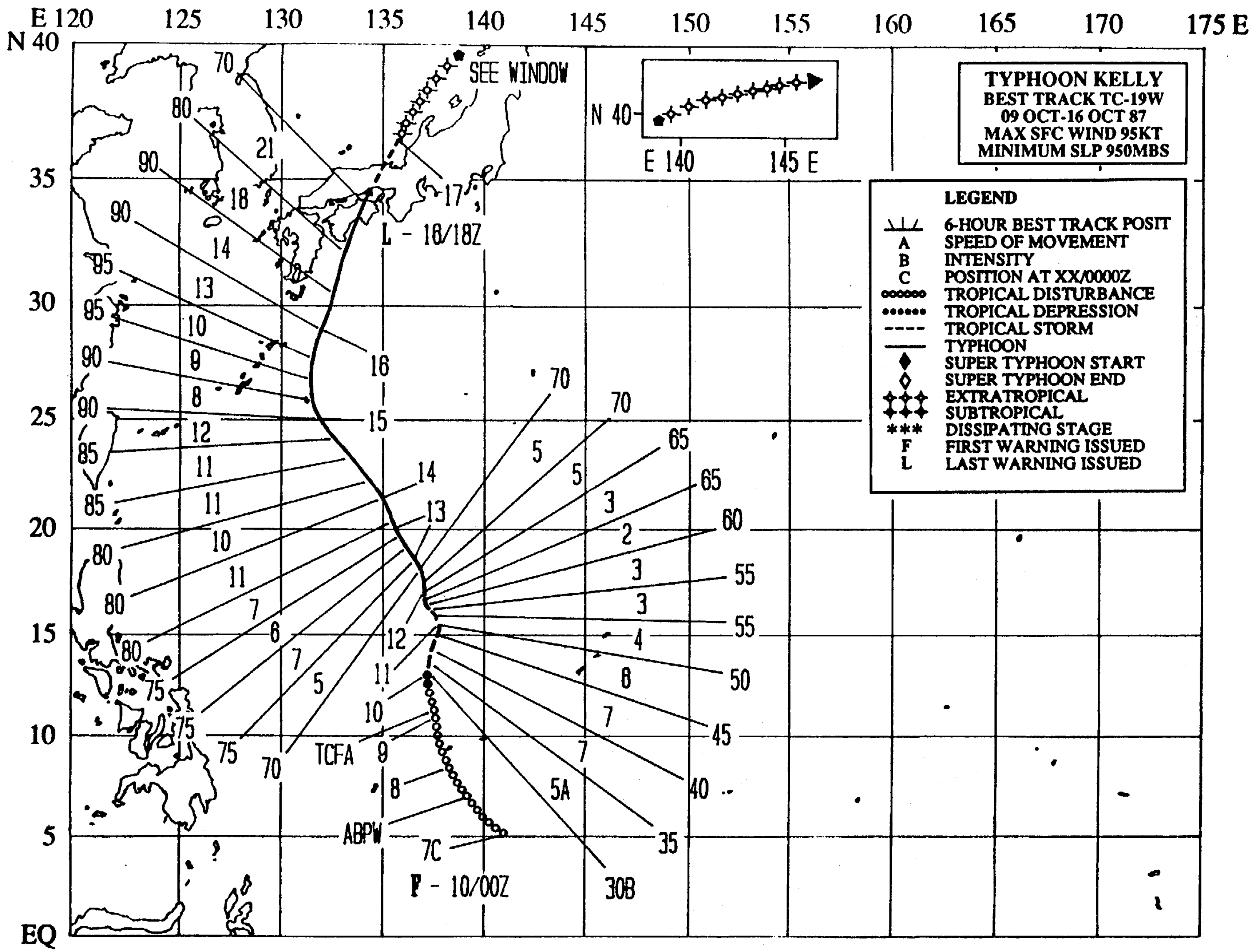


Figure 3-18-1. Tropical Storm June (18W) was the seventh and final tropical cyclone to occur in the western North Pacific during the month of September. It followed in the wake of Tropical Depression 17W. June was of significance due to the fact that, as it developed, two other tropical cyclones were also being warned on by JTWC. June struggled to develop for four days and was first noted as a suspect area on the Significant Tropical Weather Advisory (ABPW PGTW) on September 27th at 0600Z. At 280600Z, JTWC issued a Tropical Cyclone Formation Alert based on increased convective organization and satellite intensity estimates (Dvorak, 1984) of 25 kt (13 m/sec). During the next 18-hours, the convection associated with June increased significantly north of the partially exposed low-level circulation center. This, plus a satellite intensity analysis of 35 kt (18 m/sec), prompted the first warning, at 290000Z. Throughout its existence, June's upper-level outflow was restricted in the west quadrant due to the strength of Typhoon Ian's (16W) outflow. The final warning on June was issued on the 1st of October at 0000Z when the increased vertical wind shear finally stripped away the central cloudiness. The low-level remnants continued to track toward the northeast and were detected on satellite imagery until the 2nd of October. The above image shows June approximately 12-hours after reaching its peak intensity of 40 kt (21 m/sec) (292016Z September DMSP visual imagery).


TYPHOON KELLY
BEST TRACK TC-19W
09 OCT-16 OCT 87
MAX SFC WIND 95KT
MINIMUM SLP 950MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
SEE WINDOW
L - 16/18Z
F - 10/00Z
TCFA
ABPW
E 120
125
130
135
140
145
150
155
160
165
170
175 E
N 40
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TYPHOON KELLY (19W)

Typhoon Kelly was the first of two significant tropical cyclones to develop during the month of October. It moved steadily on a northward track, reaching its maximum intensity at the point of recurvature near 28 degrees North Latitude. Kelly made landfall on the Japanese island of Shikoku about 100 nm (185 km) southwest of Osaka with typhoon-force winds, then crossed west central Honshu, the main Japanese island, before moving into the Sea of Japan.

After an outbreak of three tropical cyclones in early September, an aclimatological surface ridge developed in the low latitudes which proved to be unfavorable for tropical cyclones genesis for about six days. A similar occurrence took place during the first week of October with Typhoon Ian (16W), Tropical Storm June (18W) and Typhoon Peke (02C). The strong surface ridge was the primary synoptic feature in an area normally dominated by the monsoon trough. The existence of a low-latitude ridge during the height of the tropical cyclone season appeared to be a readjustment mechanism for the unusual northward displacement of the active monsoon trough to 25 degrees North Latitude associated with both multiple-storm outbreaks.

On 6 October cross-equatorial flow returned to the low latitudes from the southern Philippine Islands to the area south of the island of Pohnpei in the eastern Caroline Islands, allowing the monsoonal trough to re-establish itself along 5 degrees North Latitude. Moonlight visual satellite imagery on 7 October indicated a circulation was developing 190 nm (352 km) south of the island of Yap (Figure 3-19-1). The 071400Z Significant Tropical Weather Advisory (ABPW PGTW) mentioned the area and classified its potential for development into a significant tropical cyclone as fair, based on an initial satellite intensity estimate (Dvorak, 1984) of 25 kt (13 m/sec) surface winds and supporting synoptic data.

Over the next 36-hours, the surface pressures at Yap and Koror (WMO 91408) were closely monitored for indications of possible development. Surface pressures at Yap dropped 1.5 mb per day, reaching a minimum of 1005 mb at 090600Z (see Figure 3-19-2).

Visual satellite imagery on 8 October indicated the low-level circulation center was displaced approximately 200 nm (370 km) south of the main convective band. As a result, satellite fixes at night, based only on infrared imagery, were unable to accurately locate the low-level center through the high cirrus shield.

A Tropical Cyclone Formation Alert was issued on the tropical disturbance at 090330Z, based on increased cirrus outflow and

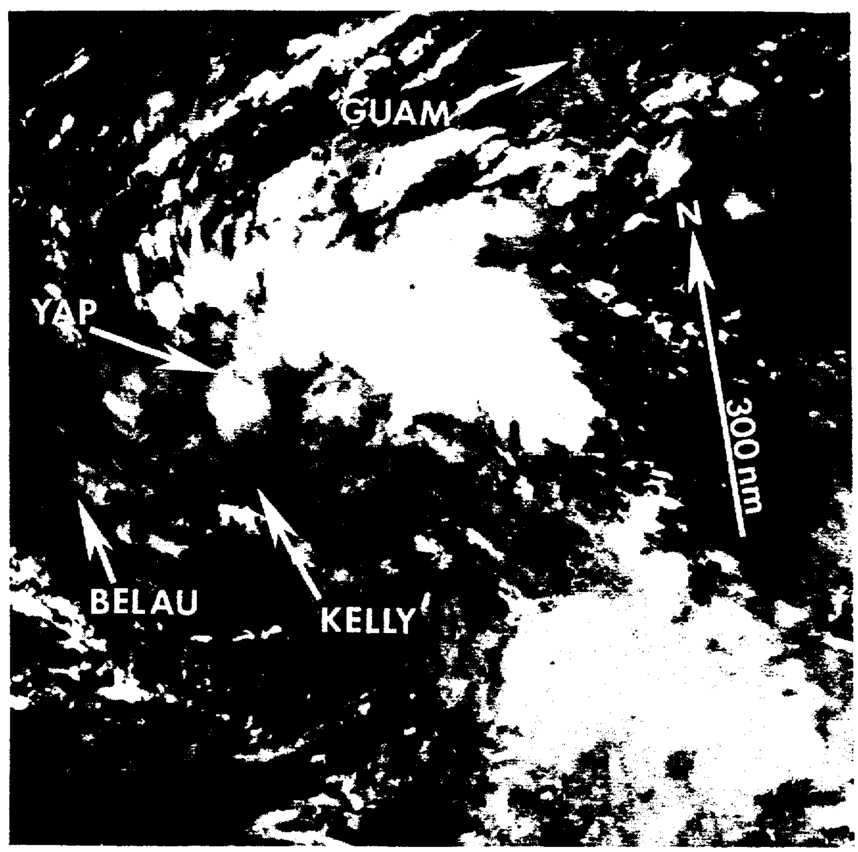


Figure 3-19-1. Moonlight visual imagery showing Typhoon Kelly at an early stage of development (071243Z October DMSP visual imagery).

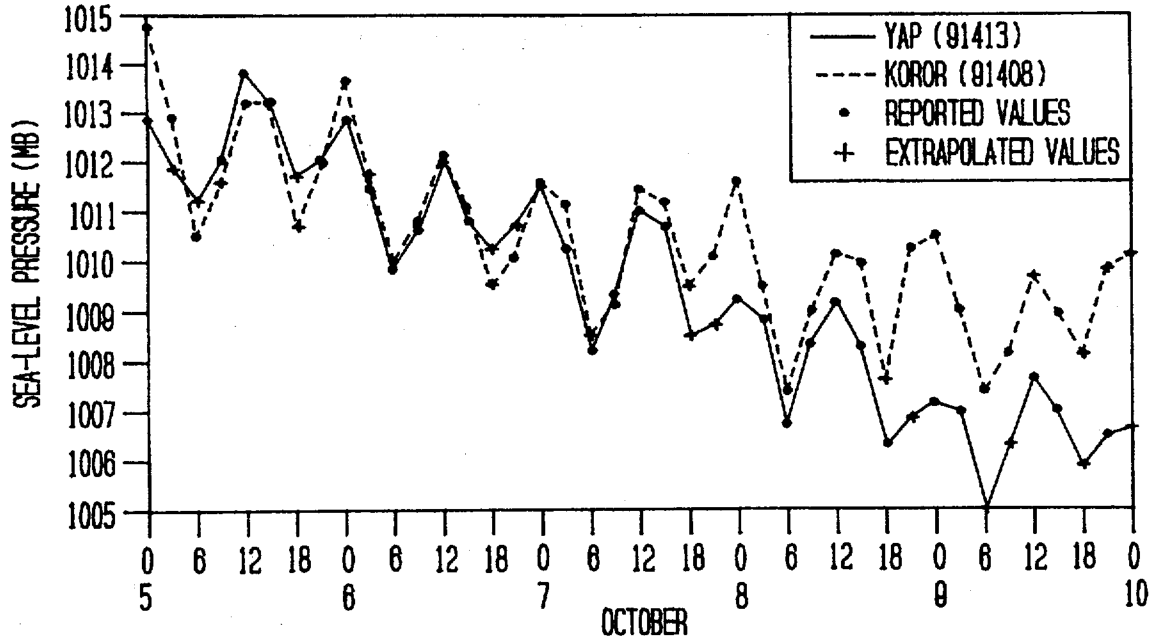


Figure 3-19-2. A plot of the surface pressures for Yap and Koror for the time period 050000Z to 100000Z October (missing values are extrapolated for continuity purposes). Although pressures were dropping at both stations, the lower surface pressures and more rapid falls at Yap indicated the low pressure center was passing close by.

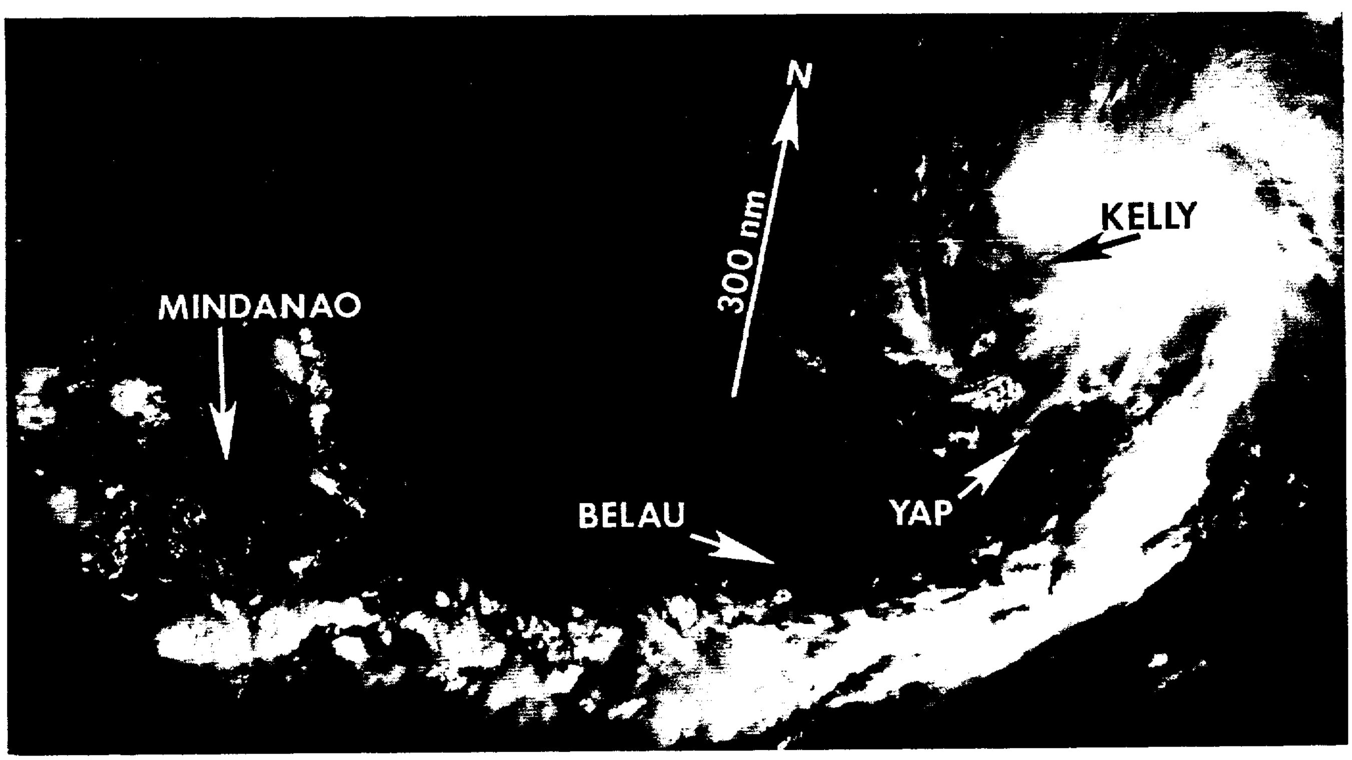


Figure 3-19-3. The low-level circulation center located west of the convective cloud mass is partially obscured by cirrus blow-off. A convective band south of Kelly identifies an area of intense convergence which extended as far west as the island of Mindanao (100043Z October DMSP visual imagery).

persistent convection around the exposed low-level circulation center. Satellite imagery over the next 24-hours showed a steady increase in the amount of convection within the cloud system. The first warning on Tropical Depression 19W was issued at 100000Z, supported by a satellite intensity estimate of 30 kt (15 m/sec). At the time of the first warning, the low-level center was still located about 60 nm (111 km) west of the dense convection (see Figure 3-19-3).

A 35 kt (18 m/sec) ship report 30 nm (56 km) north-northwest of the circulation center at 101200Z supported the earlier upgrade to tropical storm and previous satellite estimates that Kelly had attained tropical storm intensity. The low-level center position remained 95 nm (176 km) southwest of the upper-level circulation center at that time. This separation between the low- and upper-level positions

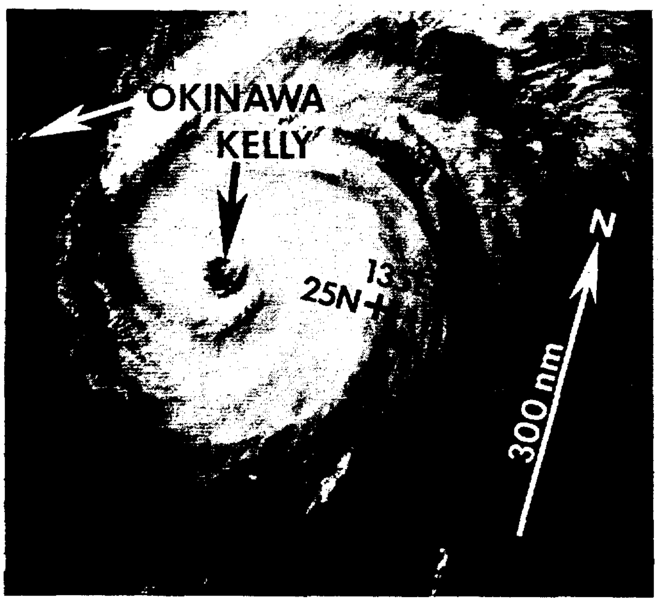


Figure 3-19-4. Typhoon Kelly approximately twelve hours prior to its reaching its maximum intensity of 95 kt (49 m/sec) (150042Z October DMSP visual imagery).

resulted in initial position relocations on the 101200Z and 101800Z warnings.

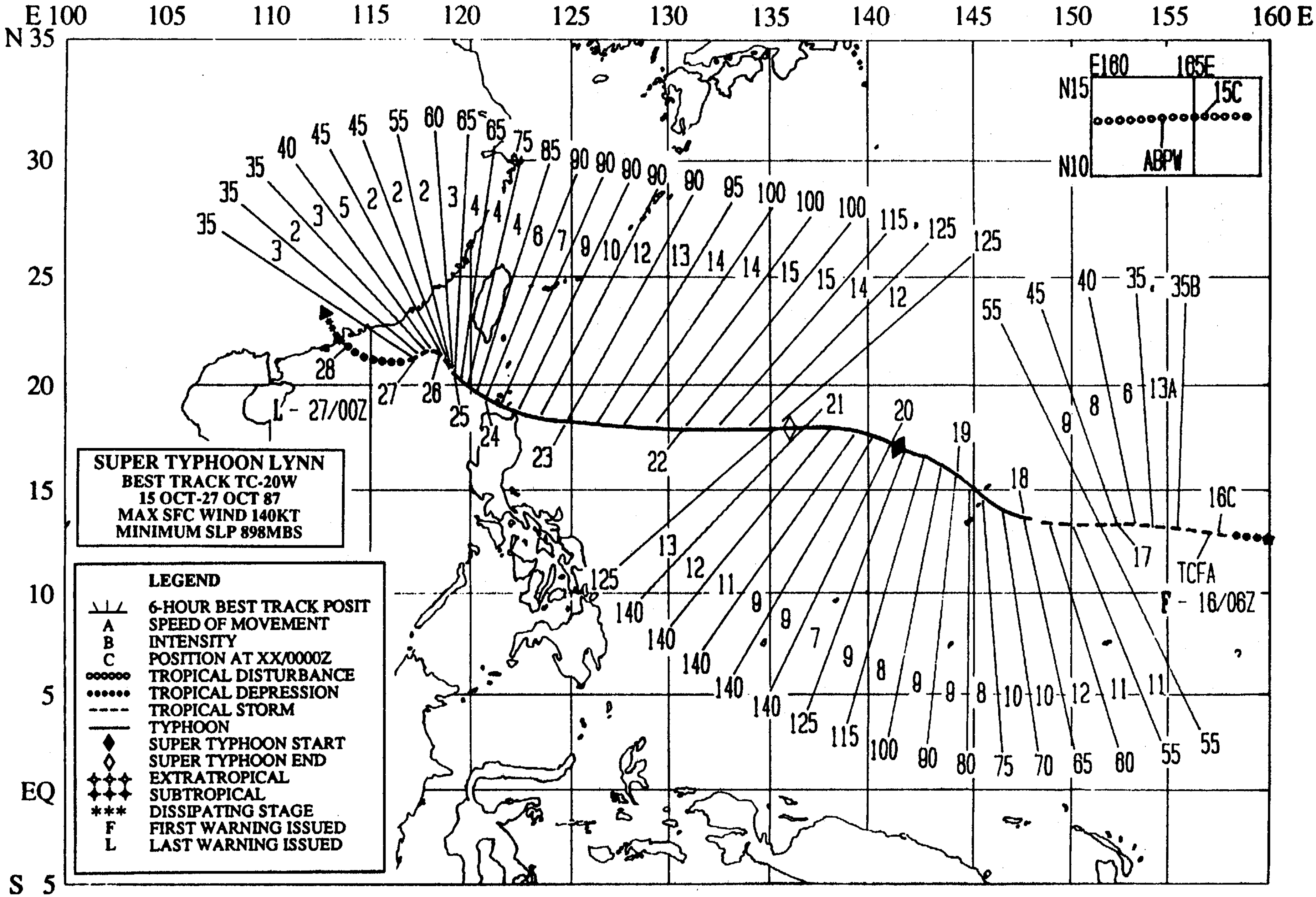
Once the low- and upper-level centers became aligned on the 11th, Kelly slowly intensified. Minimal typhoon intensity of 65 kt (33 m/sec) was reached at 120000Z. Kelly's intensity peaked at 95 kt (49 m/sec) near the point of recurvature at 151200Z (Figure 3-19-4).

By that time, Typhoon Kelly posed a serious threat to Japan. As it began to slow its forward speed and recurve near the 28th parallel, the forecast question was whether the system would continue to track northward across Japan or recurve south of Japan. Synoptic data at 150000Z indicated the upper-level westerly winds south of Japan were nearly zonal, which would tend to steer Kelly toward the east-northeast, favoring the south of Honshu scenario. This reasoning prevailed and recurvature south of Japan was forecast. By 160000Z however, a mid-level long-wave trough, anchored near the Yellow Sea, deepened as an intense short wave came in phase with the trough axis. Consequently, the steering flow ahead of the trough shifted from westerly to south-southwesterly and Kelly continued its course across Japan instead of recurving sharply northeastward.

Typhoon Kelly weakened only slightly as it began to assume extratropical characteristics on the 16th. Synoptic reports indicated Kelly did not dissipate as rapidly as implied from satellite imagery. Upper-air reports at Shiono, Japan (WMO 47778) revealed that Kelly still packed winds of 95 kt (49 m/sec) at the 850 mb level at 161200Z.

Eventually, Typhoon Kelly made landfall on the southern coast of the island of Shikoku. At least 13,000 homes were flooded and another 30 were badly damaged by mudslides triggered by as much as 20 inches (51 cm) of rain. Wind gusts were reported as high as 120 kt (62 m/sec) as typhoon-force winds battered southern Japan. At least eight people were killed.

After crossing the islands of Shikoku and Honshu, Kelly moved offshore and became extratropical over the Sea of Japan. Later, Misawa Air Base (WMO 47580), located near the northern tip of Honshu, reported maximum surface winds of 32 kt (16 m/sec) and a surface pressure of 985 mb as the extratropical low passed between the islands of Honshu and Hokkaido at 171200Z. The residual circulation of Typhoon Kelly was no longer visible on satellite imagery after 180300Z.


SUPER TYPHOON LYNN
BEST TRACK TC-20W
15 OCT-27 OCT 87
MAX SFC WIND 140KT
MINIMUM SLP 898MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 27/00Z
F - 16/06Z
TCFA
ABPW

SUPER TYPHOON LYNN (20W)

Super Typhoon Lynn was the third tropical cyclone of 1987 to produce maximum sustained surface winds of 140 kt (72 m/sec) with gusts to 170 kt (87 m/sec) and the second to attain an estimated minimum sea-level pressure (MSLP) of 898 mb (only Super Typhoons Betty (09W) and Nina (22W) were lower with a MSLP of 891 mb). It was also the fifth super typhoon of the year. Lynn, during its latter stages, also had a devastating impact on Taiwan and caused some concern in the Hong Kong area, as well.

Lynn began as a broad, poorly organized area of convection in the monsoon trough about 200 nm (370 km) north-northeast of Kwajalein Atoll in the Marshall Islands. After the convection had persisted for 24-hours, it was added as a new suspect area to the Significant Tropical Weather Advisory (ABPW PGTW) at 150600Z. Maximum sustained surface winds were estimated at 15 to 20 kt (8 to 10 m/sec); the MSLP was estimated to be 1008 mb. Over the next 18-hours, upper-level outflow and the amount of convection increased significantly as the MSLP decreased to 1001 mb. For these reasons, a Tropical Cyclone Formation Alert was issued at 160030Z, when the system was located about 360 nm (667 km) north-northwest of the island of Pohnpei in the eastern Caroline Islands. Six hours later at 160600Z, the first warning on Tropical Storm Lynn (20W) was issued, based on the satellite intensity estimate (Dvorak, 1984) of 35 kt (18 m/sec). Until 171800Z, Lynn had been moving toward the west along the southern periphery of the subtropical ridge. Before reaching tropical storm intensity, Lynn had been moving at speeds in excess of 20 kt (37 km/hr). But as it began to intensify, it decelerated. By 161200Z,

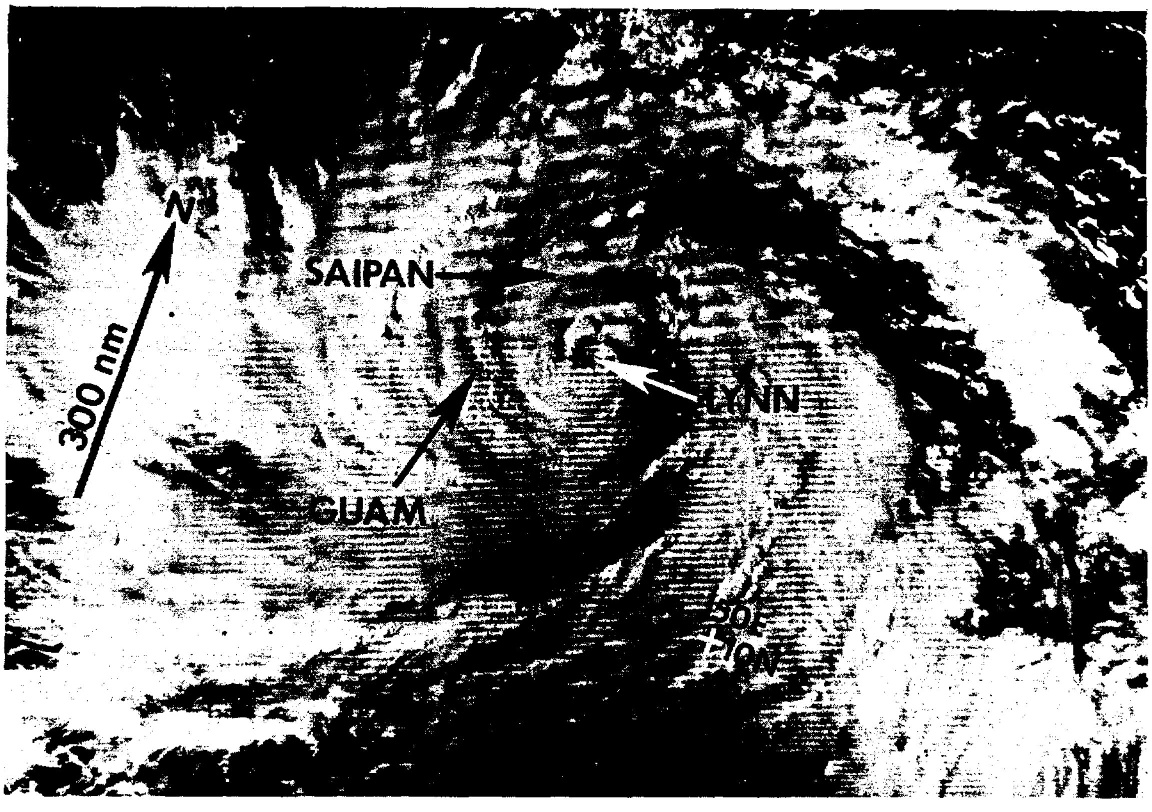


Figure 3-20-1. Tropical Storm Lynn (20W), shortly before being upgraded to typhoon intensity (180528Z October NOAA visual imagery).

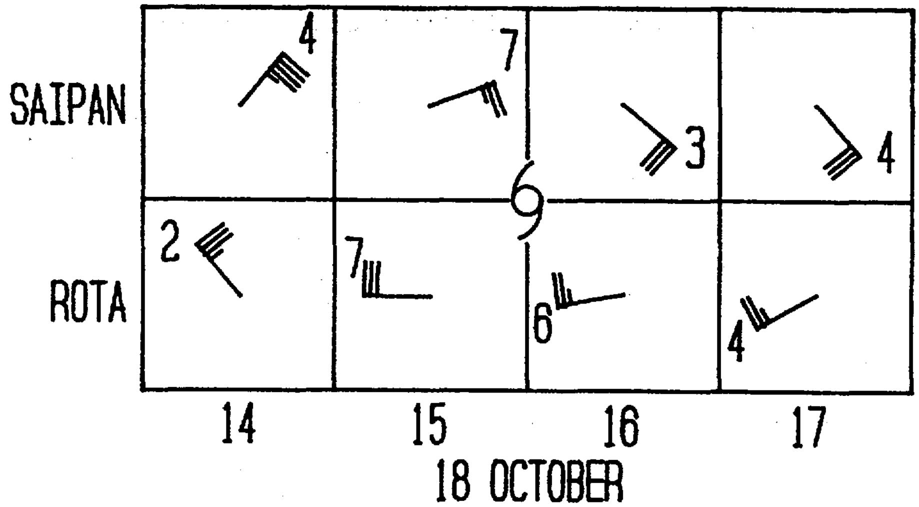


Figure 3-20-2. HANDAR observations for the islands of Saipan and Rota. These observations illustrate the closest point of approach of Typhoon Lynn to Saipan and Rota was between 181500Z and 181600Z.

Lynn was moving at a speed of only 6 kt (11 km/hr). At 180600Z, it was upgraded to typhoon status when visual and infrared satellite imagery, plus radar observations from Andersen Air Force Base on Guam, indicated Lynn had formed an eye 20 nm (37 km) in diameter (see Figure 3-20-1). Satellite analysis at that time estimated Lynn's intensity at 65 kt (33 m/sec). (Post-analysis on the system indicated that Lynn was most probably a typhoon at 180000Z.)

As it intensified, Typhoon Lynn was starting to track toward the west-northwest, away from Guam towards the island of Saipan. Consequently, JTWC amended its 180600Z warning which had forecast a more westward track. At 181200Z, Typhoon Lynn made its closest point of approach (CPA) to Guam when it tracked 75 nm (139 km) to the northeast of the island. Maximum sustained surface winds recorded on the island were 36 kt (19 m/sec) with a peak gust of 57 kt (29 m/sec) at Agana (WMO 91212). A maximum rainfall accumulation of 6.08 inches (154.4 mm) was recorded at Andersen Air Force Base (WMO 91218).

Lynn's approach had a profound effect on the island of Guam. Apra Harbor on the west side of Guam was closed after four U.S. Navy ships sortied to open waters. Military airfields evacuated aircraft and secured some aircraft in hangars. All commercial flights to and from Guam were cancelled on 18 October. Most villages on Guam reported flooding in low-lying areas, broken windows, and power and water outages. The power outages were caused mainly by the high winds which knocked vegetation onto power lines, and required several days for Guam Power Authority to repair. Perhaps the most serious damage from Typhoon Lynn was to local agriculture.

At 181500Z, Lynn made its CPA to the island of Tinian - 15 nm (28 km) southwest of the island. The automatic weather station observations at Rota, 53 nm (98 km) south-southwest of Tinian, and at Saipan, 5 nm (9 km) to the northeast of Tinian, for 181500Z and 181600Z recorded Lynn's passage(see Figure 3-20-2). Maximum sustained surface winds of 45 kt (23 m/sec), with a peak gust of 65 kt (33 m/sec) were recorded on Saipan. All commercial airline flights to and from Saipan were cancelled. Schools and government offices on Saipan were closed on 19 and 20 October. The islands of Saipan and Rota both experienced island-wide power outages on the evening of 18 October.

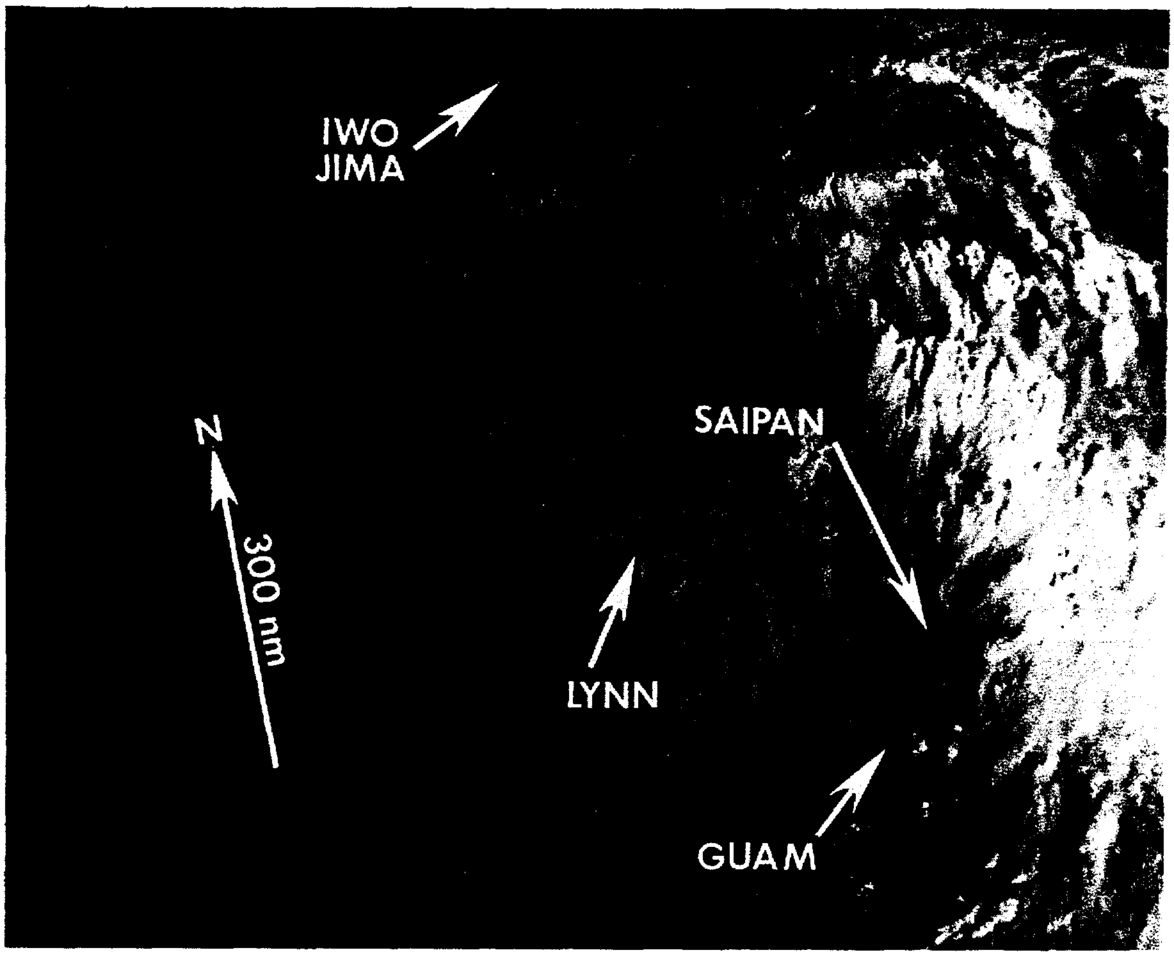


Figure 3-20-3. Super Typhoon Lynn at its maximum intensity of 140 kt (72 m/sec) (192240Z October NOAA visual imagery).

Once past the Marianas, Lynn intensified rapidly from 80 kt (41 m/sec) to its peak intensity of 140 kt (72 m/sec), reaching super typhoon intensity (130 kt or 67 m/sec) shortly after 191800Z. Super Typhoon Lynn maintained its 140 kt (72 m/sec) intensity (Figure 3-20-3) until 210000Z.

As Lynn began weakening after 210000Z, its track became westerly. Prior to that time, the forecast track had been west-northwesterly to northwesterly. Numerical guidance provided by the One-Way Interactive Tropical Cyclone Model (OTCM) appeared to be accurate. The 210600Z warning echoed this guidance, however Lynn persisted on its westward track. A closer look at the lower-tropospheric and deep-layer mean flow fields north of the typhoon provided a clue as to why Lynn was not behaving as expected. Because of Lynn's synoptic size cyclonic circulation, the integrated effect on the low- and mid-level steering flow was to eliminate the narrow subtropical ridge. Perhaps, OTCM interpreted the large-scale storm-induced circulation as being the synoptic steering flow and therefore, did not detect the narrow subtropical ridge. In contrast, Lynn was large enough to be resolved by the Navy Operational Global Atmospheric Prediction System (NOGAPS) and European Center for Medium-Range Weather Forecasting (ECMWF) numerical models, which in turn provided more accurate forecast guidance. The next warning (number 22 at 211200Z) put the forecast back "on track" and OTCM became the less-favored alternate scenario.

A close encounter by a merchant vessel on 22 October provided testimony to the fury of the typhoon. Excerpts from the ship's log include:

> *"Sea and swell were of height and steepness that we couldn't turn around anymore ... Seas are approximately 2 1/2 times the bridge height and breaking all around us. At 1000 we recorded the lowest barometric pressure of 969 HPA", (approximately 75 nm (139 km) from the center of Typhoon Lynn, at that time). "During passage of "Lynn" visibility was reduced to 000.0 mtr. Wind above comprehension ... our ears on the bridge were popping due to pressure change with pitching of vessel."*

At 240000Z, Lynn was tracking through the Luzon Strait, moving toward the northwest. From 24 through 26 October, it devastated portions of Taiwan (Figure 3-20-4). The island received high winds because of the strong pressure gradient between Lynn's low central pressure and the large high pressure area over mainland China. These high winds, caused rapid orographic lifting along the steep mountains of Taiwan, producing torrential precipitation. Although the center of Lynn passed 110 nm (204 km) to the southwest of Taiwan, it produced heavy weather over the northernmost parts of the island. News services reported 68 inches (173 cm) of rainfall on the capital city of Taipei from 24 to 26 October! In Taipei, torrential rainshowers caused landslides that smashed houses and killed 14 people. Over 2,200 people were stranded by floodwaters from

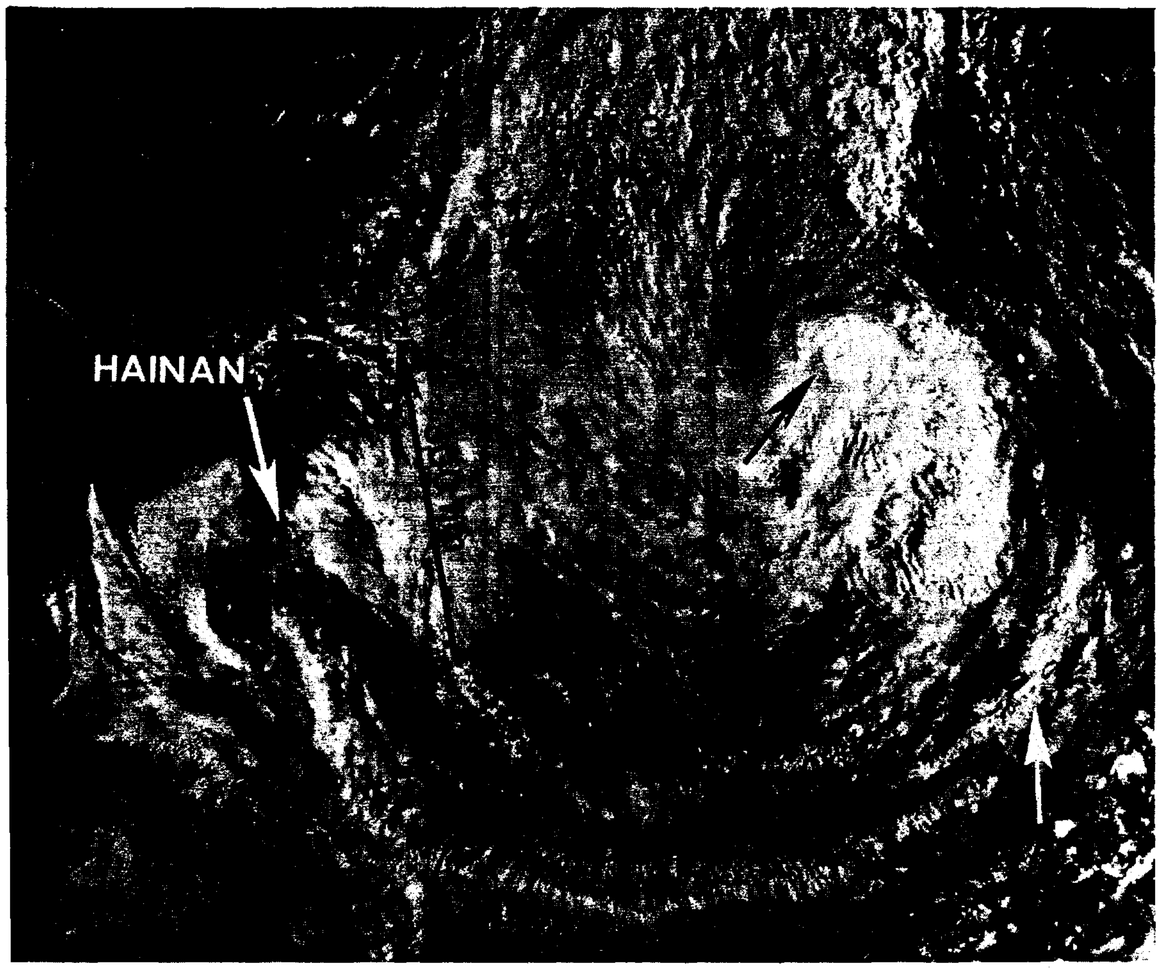
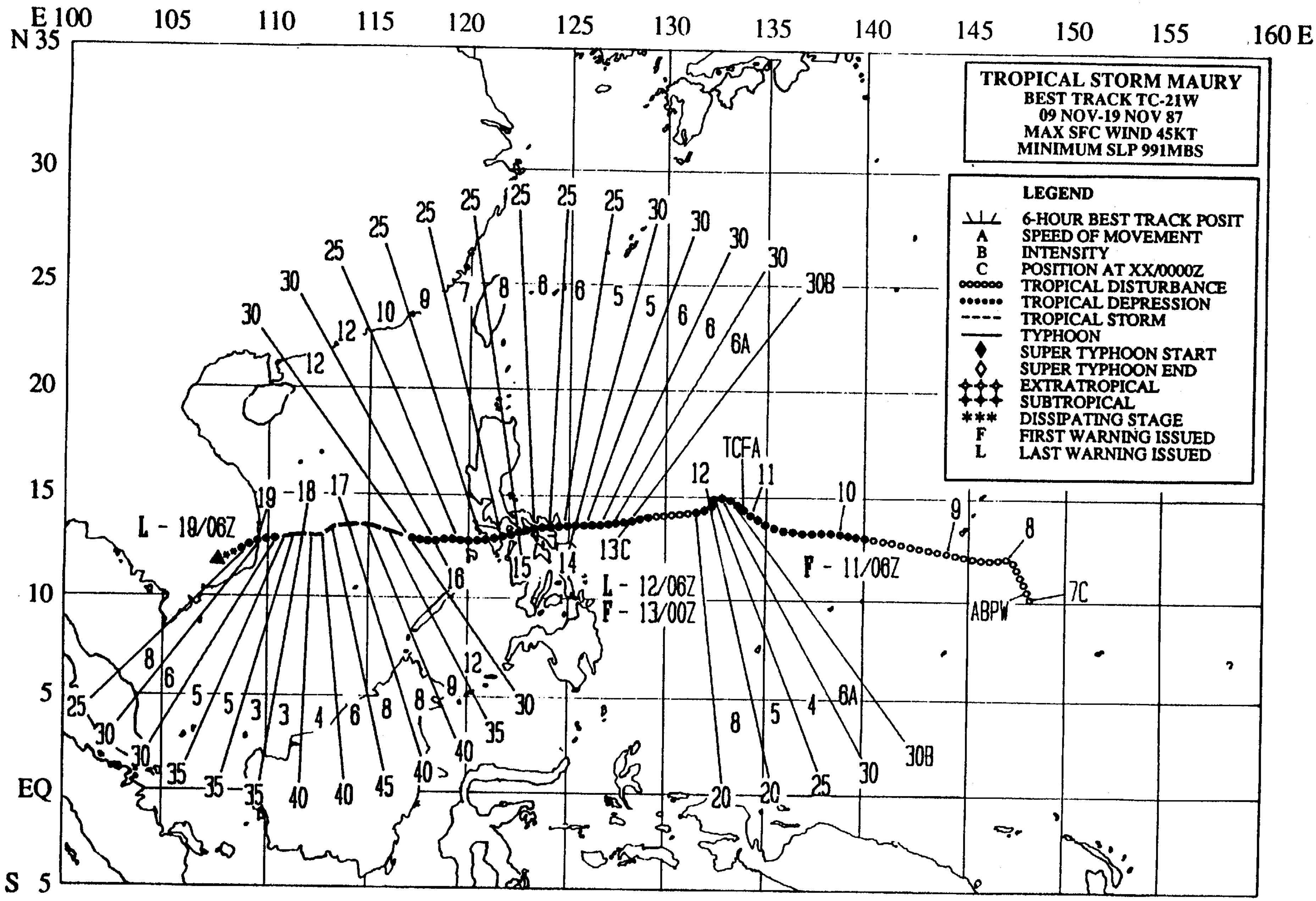


Figure 3-20-4. Tropical Storm Lynn during its rapid weakening phase (250013Z October NOAA visual imagery).

the Keelung River in Taipei making travel impossible. The Central Weather Bureau in Taipei reported 84 kt (43 m/sec) maximum sustained surface winds on 24 October and 61 kt (31 m/sec) maximum sustained surface winds on 25 October. The port city of Keelung reported over five million dollars worth of damage from Lynn. Lynn created 20 ft (6.1 meter) high waves at Hengchun on the extreme southern tip of Taiwan and nine children were swept away. The result of Lynn's passage was Taiwan's worst flooding in 40 years; 42 people perished and 18 were reported missing.

Visual and infrared satellite imagery at 260300Z, indicated that Lynn was being sheared apart. Subsequent satellite imagery showed the low-level circulation center moving toward the west-southwest away from the convective mass. At 270000Z, the final warning was issued on Tropical Depression 20W (Lynn). Although the tropical cyclone had lost its central convection, the remaining low-level circulation center still had an impact on the Hong Kong area. The wind speeds and precipitation amounts the Hong Kong area received were higher than expected. The strong pressure gradient between the residual low offshore and the high over mainland China fostered gales along the south coast. The Hong Kong (WMO 45005) 280000Z upper-air sounding revealed maximum winds of 55 kt (28 m/sec) from the east-southeast, at 900 and 850 mb. The low tracked south of Hong Kong, into the Pearl River Estuary and eventually dissipated over land.


TROPICAL STORM MAURY
BEST TRACK TC-21W
09 NOV-19 NOV 87
MAX SFC WIND 45KT
MINIMUM SLP 991MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
S 5
L - 19/06Z
L - 12/06Z
F - 13/00Z
F - 11/06Z
TCFA
ABPW
7C
13C
30B
6A

TROPICAL STORM MAURY (21W)

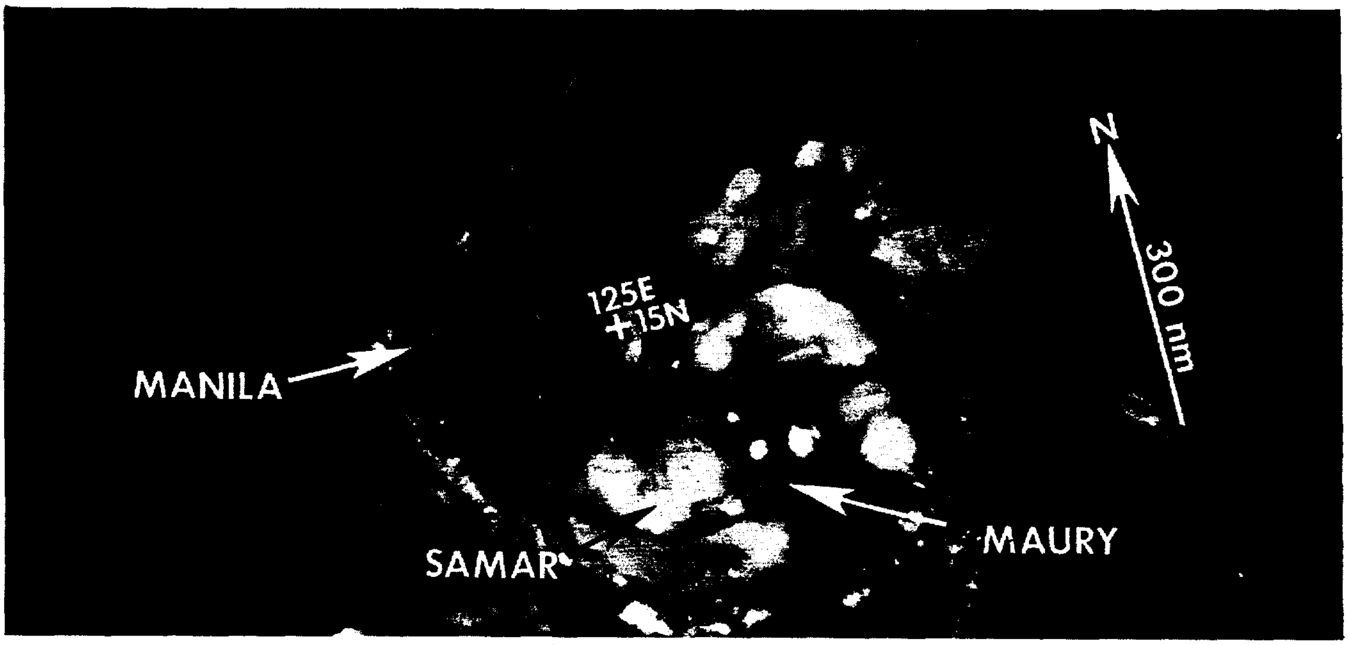
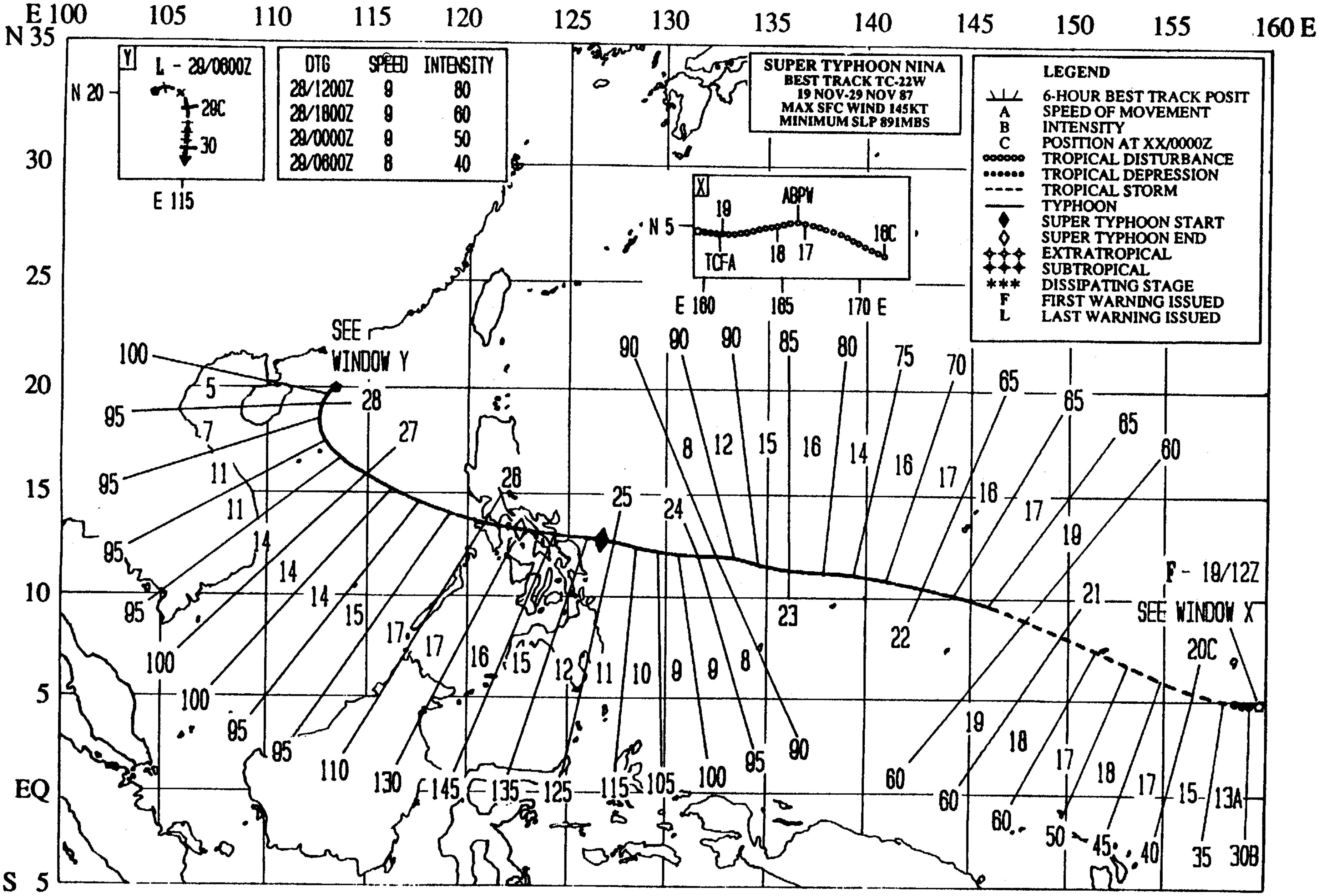


Figure 3-21-1. Tropical Storm Maury was a relatively weak, but persistent, tropical cyclone that tracked westward across the Philippine and South China Seas. It was the first of three significant tropical cyclones to form in November and the second system of the year to regenerate over water. Tropical Storm Maury formed in early November in the western North Pacific near-equatorial trough about 300 nm (556 km) to the southeast of Guam. It was first detected as an area of deep convection with a well-defined, low-level circulation center but a poor upper-level outflow and was first mentioned on the Significant Tropical Weather Advisory (ABPW PGTW) at 070600Z. Due to unfavorable vertical shear, the system appeared to have a poor chance for further development and showed little sign of intensification over the next three days. However, the central convection did increase. At 110130Z, a Tropical Cyclone Formation Alert (TCFA) was issued. The first warning on Tropical Depression 21W followed at 110600Z, based upon the presence of a central dense overcast and satellite intensity estimates (Dvorak, 1984) of 30 kt (15 m/sec). Tropical Depression 21W maintained its organization and convection over the next 6- to 9-hours, but began to slow and weaken, as an eastward-moving, low- to mid-level trough passed to the north. At 120000Z, JTWC issued a final warning, but continued to monitor the remnants for possible regeneration. With the trough in the polar westerlies displaced to the east, the convection in the remnants of Tropical Depression 21W flared-up, prompting the issuance of a second TCFA at 130330Z. Almost immediately, an abbreviated warning (the first of the year) was issued (at 130530Z) as the cloud system gained in organization. Over the next 12-hours, the regenerated Tropical Depression 21W maintained its organization, but remained below tropical storm intensity (see above image). By 131800Z, as it approached the Philippine Islands, Tropical Depression 21W showed signs of becoming less organized, as the central convection diminished. Prior to Tropical Depression 21W crossing the Philippine Islands, JTWC altered its forecast philosophy from "dissipating over land", to "regeneration" in the South China Sea. As Tropical Depression 21W entered the South China Sea, the deep convection increased significantly. Dvorak satellite intensity analysis at 161200Z estimated maximum surface winds of 35 kt (18 m/sec), prompting JTWC to upgrade Tropical Depression 21W to Tropical Storm Maury (21W). Maury tracked westward across the South China Sea and reached the maximum intensity of 45 kt (23 m/sec) at 170600Z. Later, it made landfall on the southeast coast of Vietnam 25 nm (46 km) north of Cam Ranh Bay at 190400Z. The final warning was issued at 190600Z as Maury dissipated over land. No reports of severe damage or loss of life were received (131009Z November DMSP infrared imagery).



SUPER TYPHOON NINA
BEST TRACK TC-22W
19 NOV-29 NOV 87
MAX SFC WIND 145KT
MINIMUM SLP 891MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
Y
L - 29/0600Z
N 20
28C
30
E 115
DTG SPEED INTENSITY
28/1200Z 9 80
28/1800Z 9 60
29/0000Z 9 50
29/0600Z 8 40
X
N 5
19
ABPW
18C
TCFA
18
17
E 160
165
170 E
SEE WINDOW Y
SEE WINDOW X
F - 19/12Z
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
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10
5
EQ
S 5

SUPER TYPHOON NINA (22W)

Super Typhoon Nina was the most intense and most destructive tropical cyclone to develop in the western North Pacific in 1987. During its track toward the west, it devastated the Truk Atoll in the eastern Caroline Islands, decimated the north central Philippine Islands and then executed a final dramatic loop in the South China Sea south of Hong Kong. Nina was the second of three significant tropical cyclones to develop during November.

Nina developed in low latitudes just west of the dateline. At 150000Z, satellite intensity analysis (Dvorak, 1984) estimated a cloud system center had maximum sustained surface winds of 25 kt (13 m/sec). For two days this disturbance showed marked diurnal fluctuations in convection. It was first mentioned on the 170600Z Significant Tropical Weather Advisory (ABPW PGTW) as a system with fair potential to develop into a significant tropical cyclone. The system displayed good upper-level outflow and increasing convection over a broad area.

A Tropical Cyclone Formation Alert was issued at 190100Z as deep convection consolidated in the center of the tropical disturbance. Synoptically, the system appeared to be well-established in the low levels up to 400 mb (Figure 3-22-1) with 25 to 30 kt (13 to 15 m/sec) easterlies aloft. With speed and directional divergence aloft, Nina continued its rapid organization. At 191200Z, the first warning was issued on Tropical Depression 22W. By that time, Nina had formed a curved band of convection. Satellite imagery (Figure 3-22-2) suggested unrestricted upper-level outflow over the system; however, the upper-level rawinsonde reports showed that the anticyclonic circulation (at 200 mb) was displaced to the east of the center of cirrus outflow (Figure 3-22-3).

At the time of the first warning, working plots of satellite fix positions indicated Nina was slowing down its west-northwestward movement. (To the contrary, post-analysis revealed that Nina did not slow down while intensifying but actually accelerated slightly.

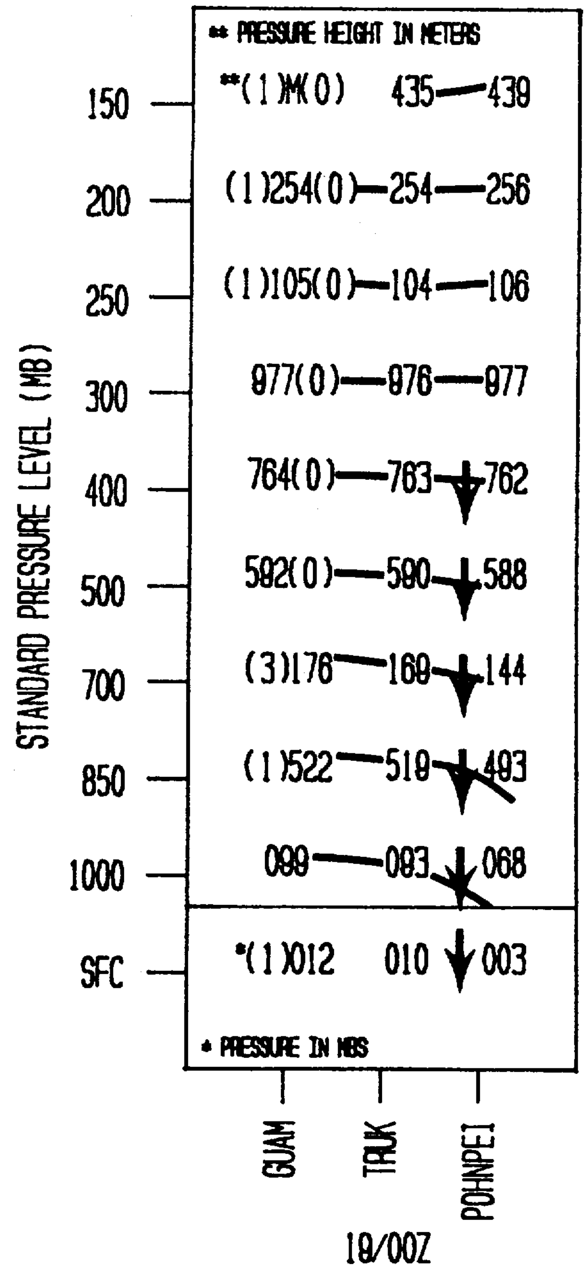


Figure 3-22-1. Heights of the standard pressure levels and surface pressure at Pohnpei (WMO 91348), Truk (WMO 91334) and Guam (WMO 91217) at 190000Z. At this time, Nina was 230 nm (426 km) southeast of the island of Pohnpei. In comparison with Truk and Guam, the lower heights at Pohnpei (WMO 91348) at the 400 mb level and below are due to the approaching tropical cyclone.

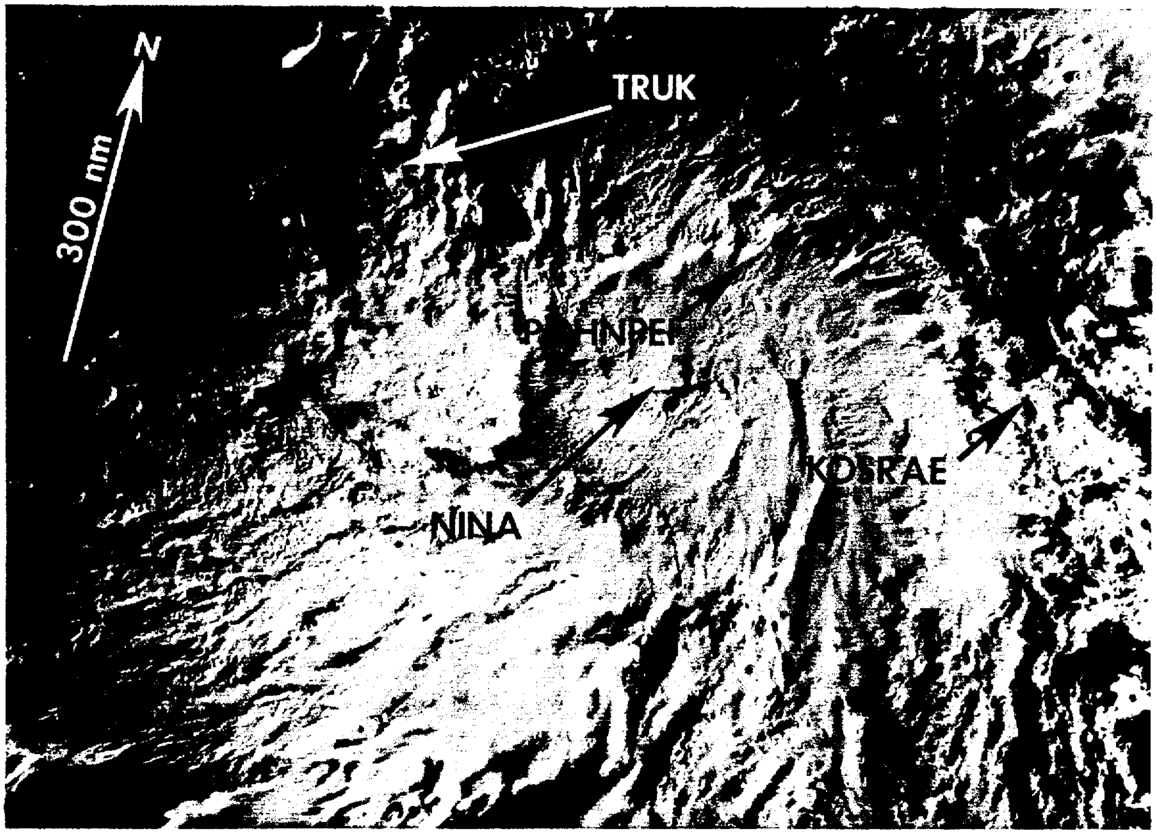


Figure 3-22-2. Satellite imagery indicating improving organization in the central convection and good upper-level outflow associated with the tropical disturbance that was to become Nina (191457Z November DMSP visual imagery).

This acceleration along the working best track would greatly affect the forecast movement. For example, if a cyclone is moving at 2 kt (4 km/hr) faster than forecast, it will travel in 72-hours an additional 144 nm (267 km).)

Nina continued to intensify and accelerate. By the time of the second warning at 191800Z, Nina was upgraded to tropical storm intensity. More rapid westward movement was supported by upper-level data at Guam (WMO 91217), Truk (WMO 91334) and Pohnpei (WMO 91348), which indicated 30 kt (15 m/sec) easterly mid-level flow during this time (Figure 3-22-4). At 201600Z, Nina passed 40 nm (74 km) south of Moen Island in the Truk Atoll while moving west-northwestward at 18 kt (33 km/hr). Satellite intensity analysis estimated winds between 45 and 50 kt (23 to 26 m/sec). Maximum winds reported at Moen Island were 60 kt (31 m/sec) with gusts up to 80 kt (41 m/sec). (Note: The difference in intensity may be due to the fact that winds in the right front quadrant of a tropical cyclone are a combination of its kinetic energy and the vector addition of its forward movement.) The lowest pressure recorded was 987 mb, which correlates (Atkinson and Holliday, (1977)) to 50 kt (26 m/sec).

Nina passed the Truk Atoll during the early morning hours on the 21st of November. Civil Action Teams reported that five people were killed, 38 seriously injured, and most of the more than 40,000 residents were homeless and without electrical power. The Truk Atoll was declared a federal disaster area in order to compensate for the $30 to $40 million in damage to housing, businesses and agriculture. In addition, U. S. Armed Forces airlifted supplies into the ravaged islands.

After Nina passed the Truk Atoll, it slowly decelerated. The rate of intensification also slowed. Nevertheless, Nina was upgraded to typhoon intensity at 211200Z. Nina passed

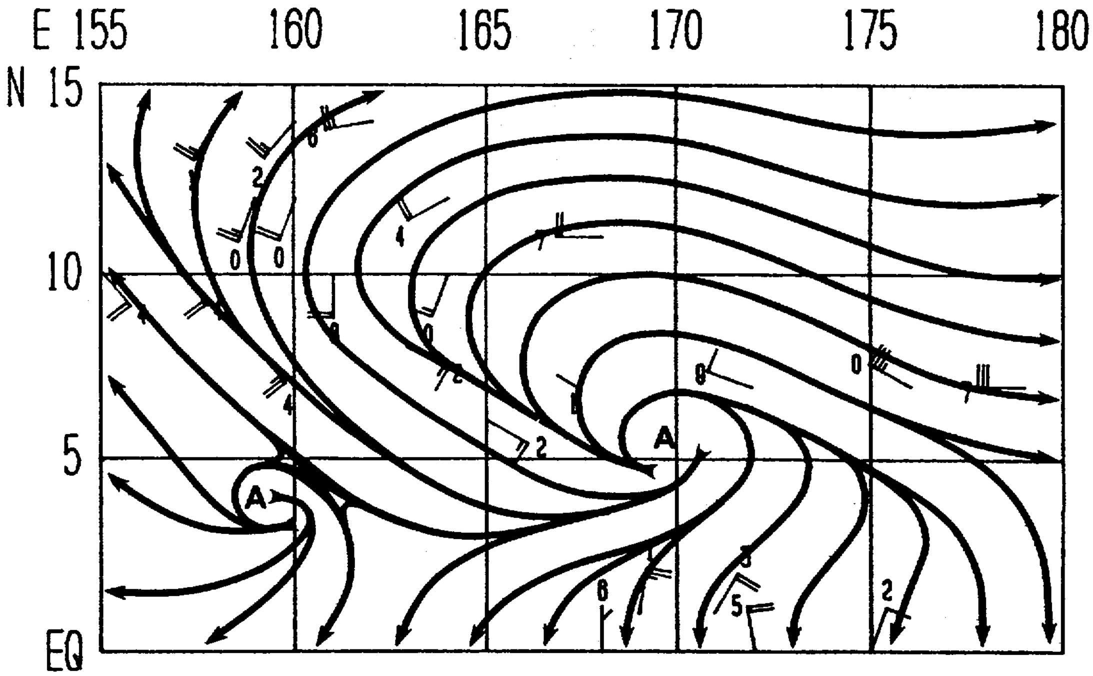


Figure 3-22-3. Synoptic data at 191200Z, showing the center of the upper-level anticyclonic circulation at 200 mb located considerably east of the center of the cirrus outflow associated with Tropical Depression 22W.

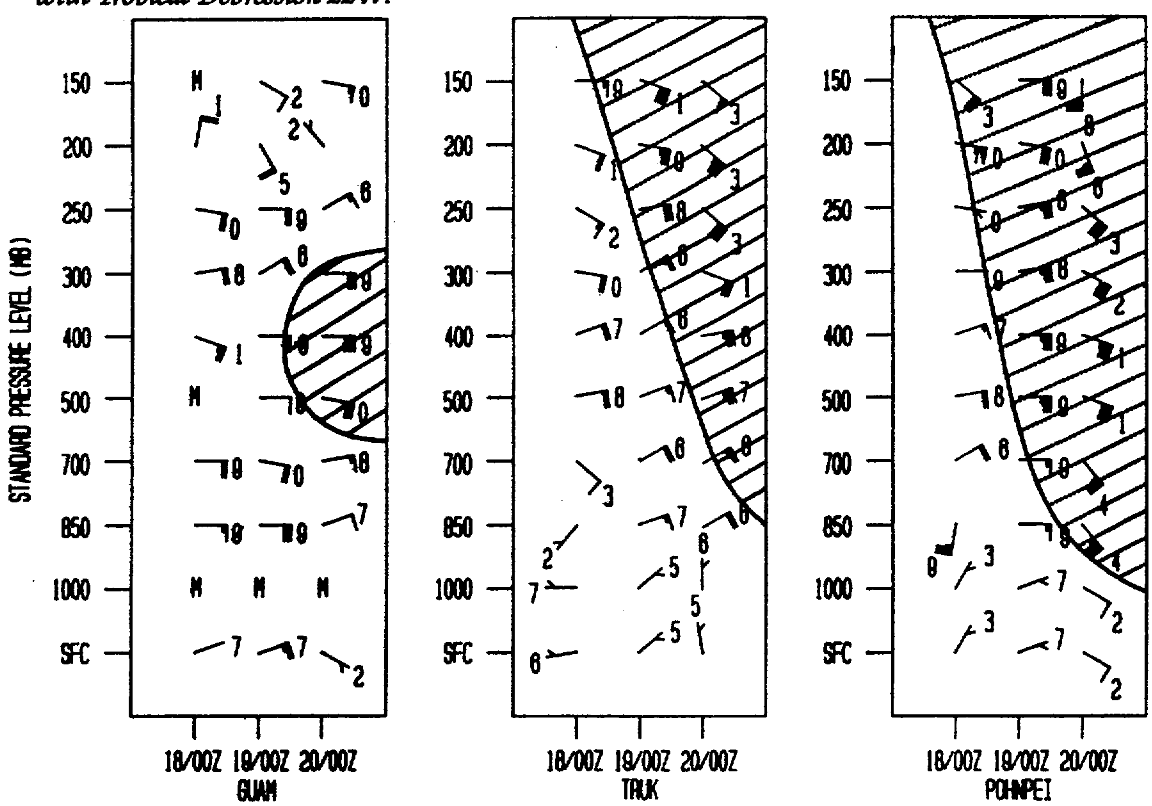


Figure 3-22-4. Upper-air winds and heights at standard pressure levels for Guam (WMO 91217), Truk (WMO 91334) and Pohnpei (WMO 91348) for the period 180000Z to 200000Z. Notice the 30 kt (15 m/sec) mid-level easterlies which would support the rapid movement of Nina toward the west.

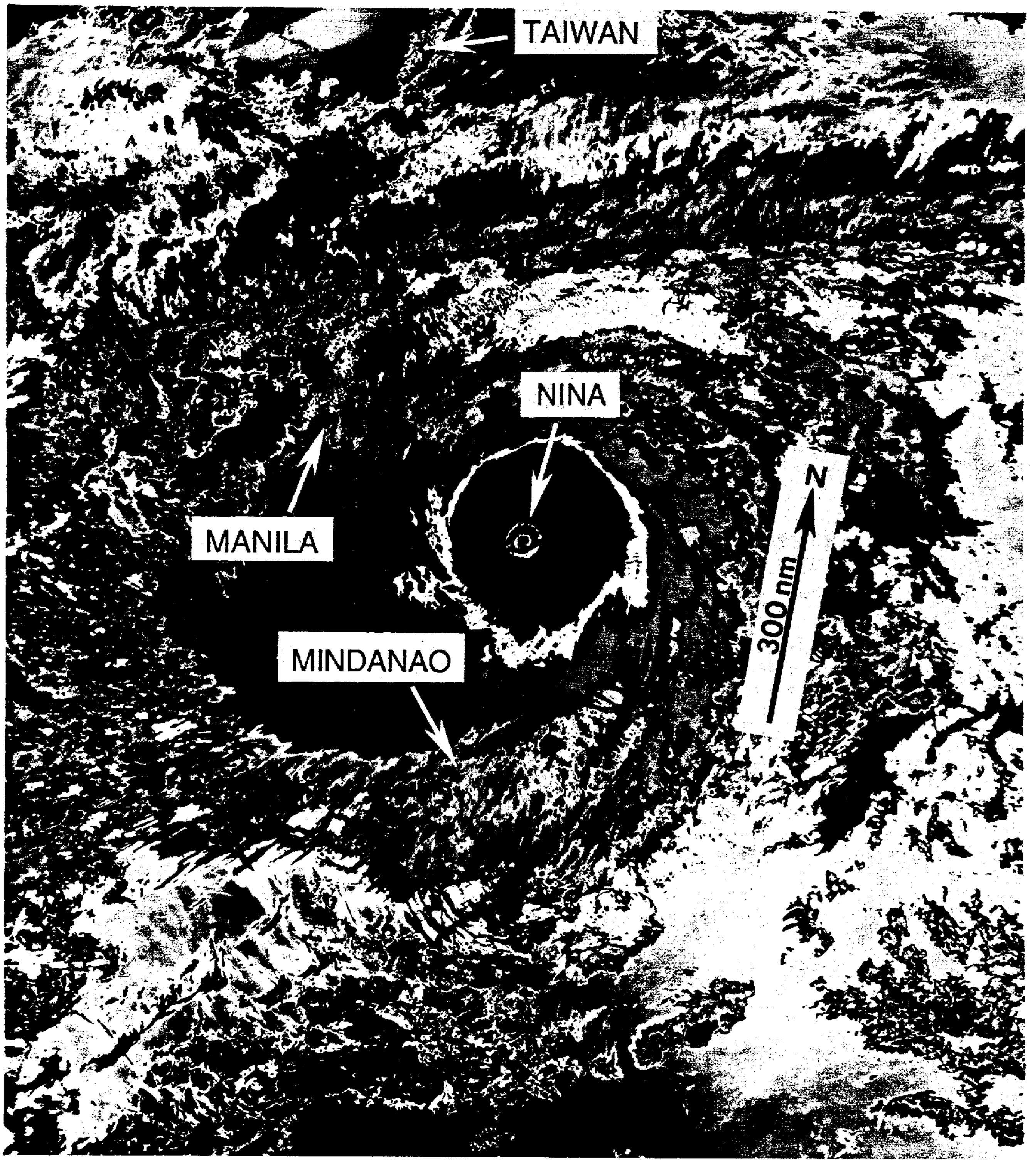


Figure 3-22-5. Satellite imagery showing the well-defined eye of Super Typhoon Nina as it approached the Philippine Islands (250701Z November NOAA visual imagery).

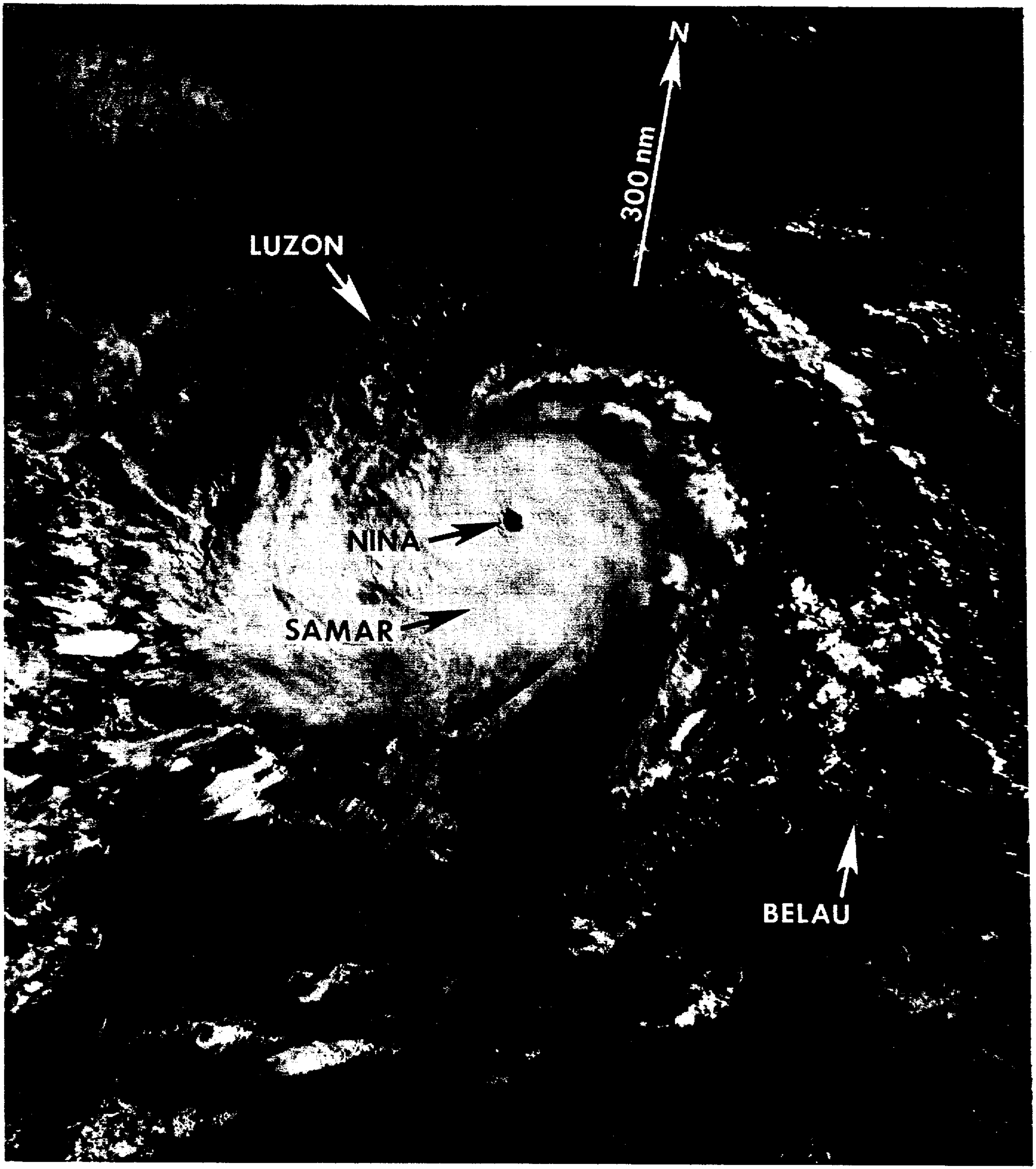


Figure 3-22-6. Matching infrared image for visual in Figure 3-22-5 (250701Z November NOAA infrared imagery).

Prognostic Reasoning

DTG	Direction	Guidance	Speed
260000Z	WNW for 36-hrs then NW	OTCM & COSMOS	Decelerating
261200Z	WNW 12- to 18-hrs then NW	Break in 400 mb ridges	-----
Alternate scenario:	Recurve in 48- to 72-hrs	OTCM	-----
2nd alternate scenario:	Move west	CSUM	-----
270000Z	WNW for 48-hrs	NE surge interaction, ECMWF & NORAPS & HPAC	Slowly decelerating
Alternate scenario:	West	---------	------
271200Z	NW then West	NE surge, NORAPS & NOGAPS & ECMWF	------
280000Z	North for 27-hrs then West	NE surge, 700 & 400 mb progs & HPAC	------
281200Z	ENE	Strong mid- to upper-level westerly flow & CSUM	Accelerating
290000Z	ENE	Strong mid- to upper-level southwesterly flow	Accelerating

Figure 3-22-7. Abbreviated Prognostic Reasoning for the 260000Z through 290000Z November time period.

60 nm (111 km) north of the island of Ulithi and 95 nm (176 km) north of Yap at 221000Z and 221600Z, respectively. Later, on November 25th, an overflying Navy aircraft observed moderate flood damage to the Ulithi's agricultural areas. Twenty percent of the buildings had received structural damage. No damage was reported on Yap.

Nina began to slowly accelerate and rapidly intensify (Holliday and Thompson, 1979), dropping approximately 4 mb per six hours, as it approached the Philippine Islands. Beginning at 241200Z, Nina began to explosively deepen (Holliday and Thompson), dropping approximately 8 mb per six hours. Nina displayed a symmetrical eye that was 18 nm (33 km) in diameter (Figures 3-22-5 and 3-22-6). Nina slammed into the southern tip of Luzon at 251500Z with maximum winds estimated at 145 kt (75 m/sec) with gusts to 175

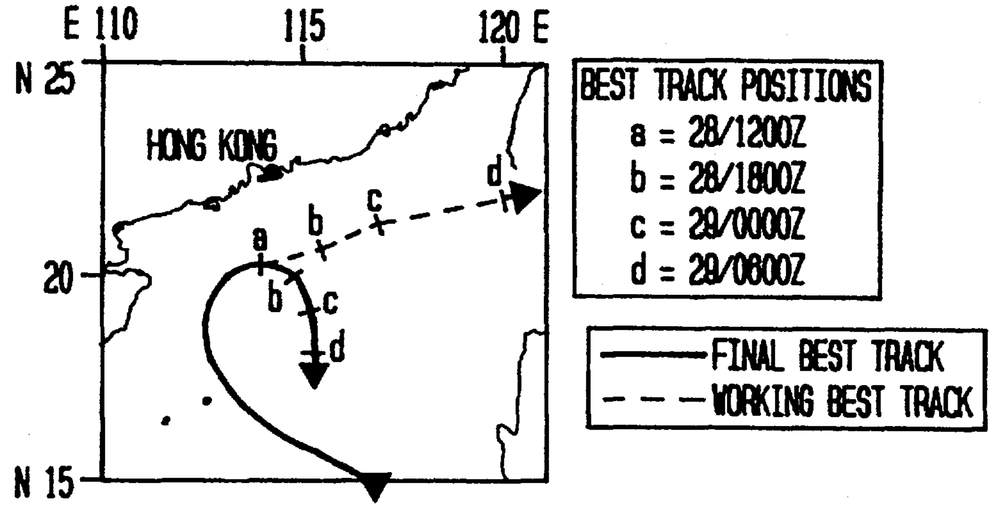


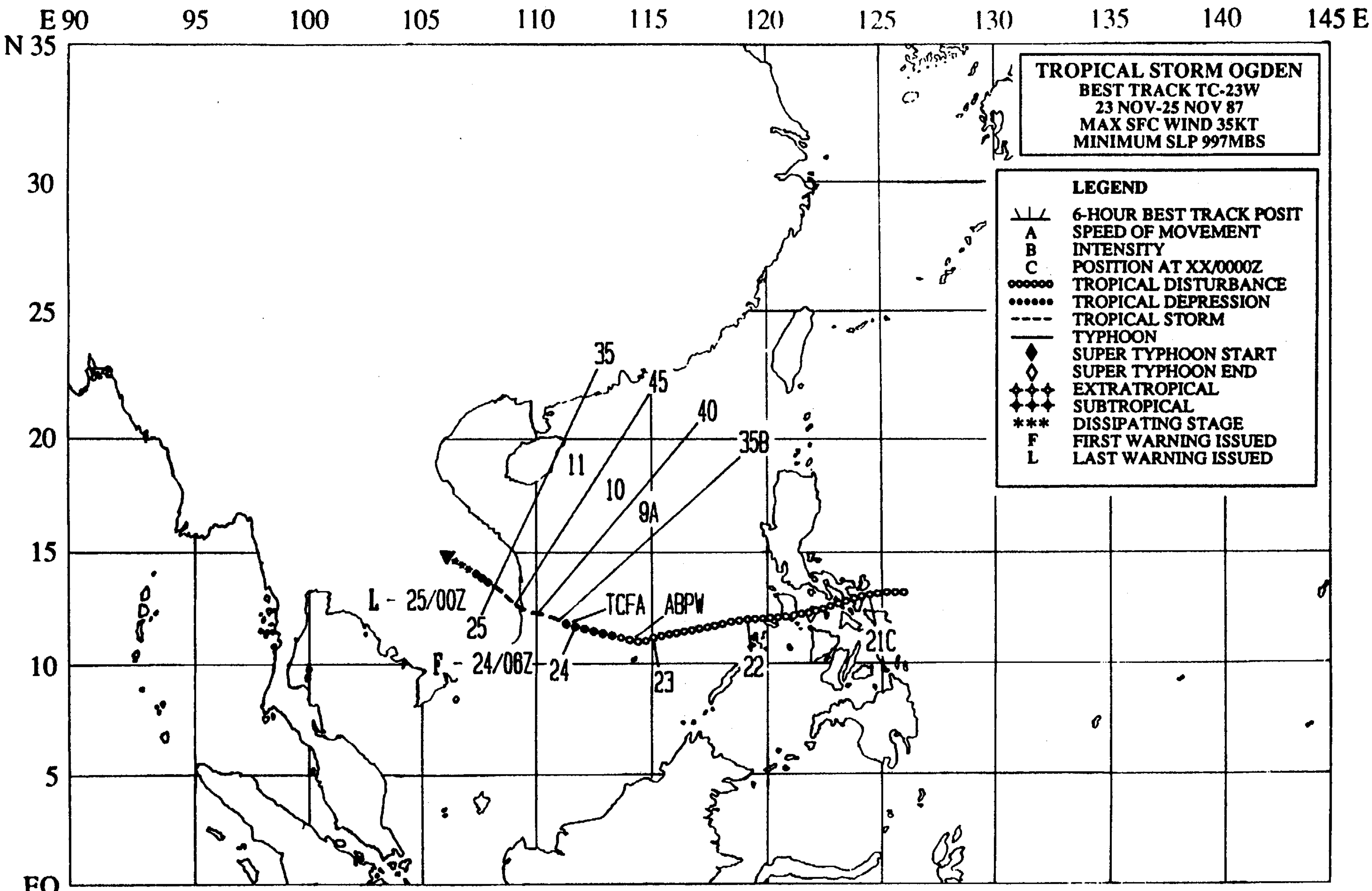
Figure 3-22-8. Difference between the working and final best tracks as Nina was sheared apart by the strong surge of the Northeast Monsoon.

kt (90 m/sec). At least 687 people perished in the north central Philippine Islands. As with the Truk Atoll, Nina struck at night. Philippine authorities declared a state of emergency for 18 provinces that were battered by Nina. Overall more than 500,000 people were either rendered homeless, evacuated, or lost their sources of income. Croplands were heavily damaged. News sources reported that Nina was the most destructive typhoon to hit the Philippine Islands in nearly 20 years.

Nina traversed between the islands of Luzon and Mindoro and entered the South China Sea with 95 kt (49 m/sec) winds. Although satellite imagery could not detect an eye, land-based radar continued to track the cloud covered eye. Shortly thereafter, Nina was packing 100 kt (51 m/sec) winds.

Once Nina was in the South China Sea, the forecast philosophy attempted to keep up with the changing synoptic situation. Figure 3-22-7 provides an abbreviated look at the specifics of each prognostic reasoning message for the 260000Z through 290000Z November time period. Basically what initially appeared to be straight-forward, wasn't! The decoupling of Nina's lower- and upper-level circulations developed into a complex event; culminating in the 270000Z prognostic reasoning message, which became a classic example of being wrong for all the right reasons. The net result was a very tense situation for Hong Kong and the southern China coast.

As the system began to move northward, an eye became visible at 280300Z. Within 6- to 12-hours, Nina was sheared apart by the shallow, but strong, low-level surge in the northeast monsoon flow and strong westerly winds at the mid- and upper-levels. During the shearing, the deep convection, which was poorly defined and being positioned as an upper-level circulation by satellite, accelerated east-northeastward along the quasi-stationary front. As a consequence, the forecast philosophy embraced a cloud system moving rapidly through the Luzon Strait and becoming extratropical. (Post-analysis found that the low-level most probably separated from the upper-level circulation center at 280600Z. This resulted in a 340 nm (630 km) difference at 24-hours between the working best track and the final best track points as seen in Figure 3-22-8.) The upper-level cloudiness did move east-northeastward; however, the low-level circulation center executed an anticyclonic loop and headed slowly southward with the monsoonal flow. The residual low-level vorticity and cloudiness rapidly dissipated over the South China Sea.


TROPICAL STORM OGDEN
BEST TRACK TC-23W
23 NOV-25 NOV 87
MAX SFC WIND 35KT
MINIMUM SLP 997MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 90
95
100
105
110
115
120
125
130
135
140
145 E
N 35
30
25
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EQ
35
45
40
35B
11
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TROPICAL STORM OGDEN (23W)

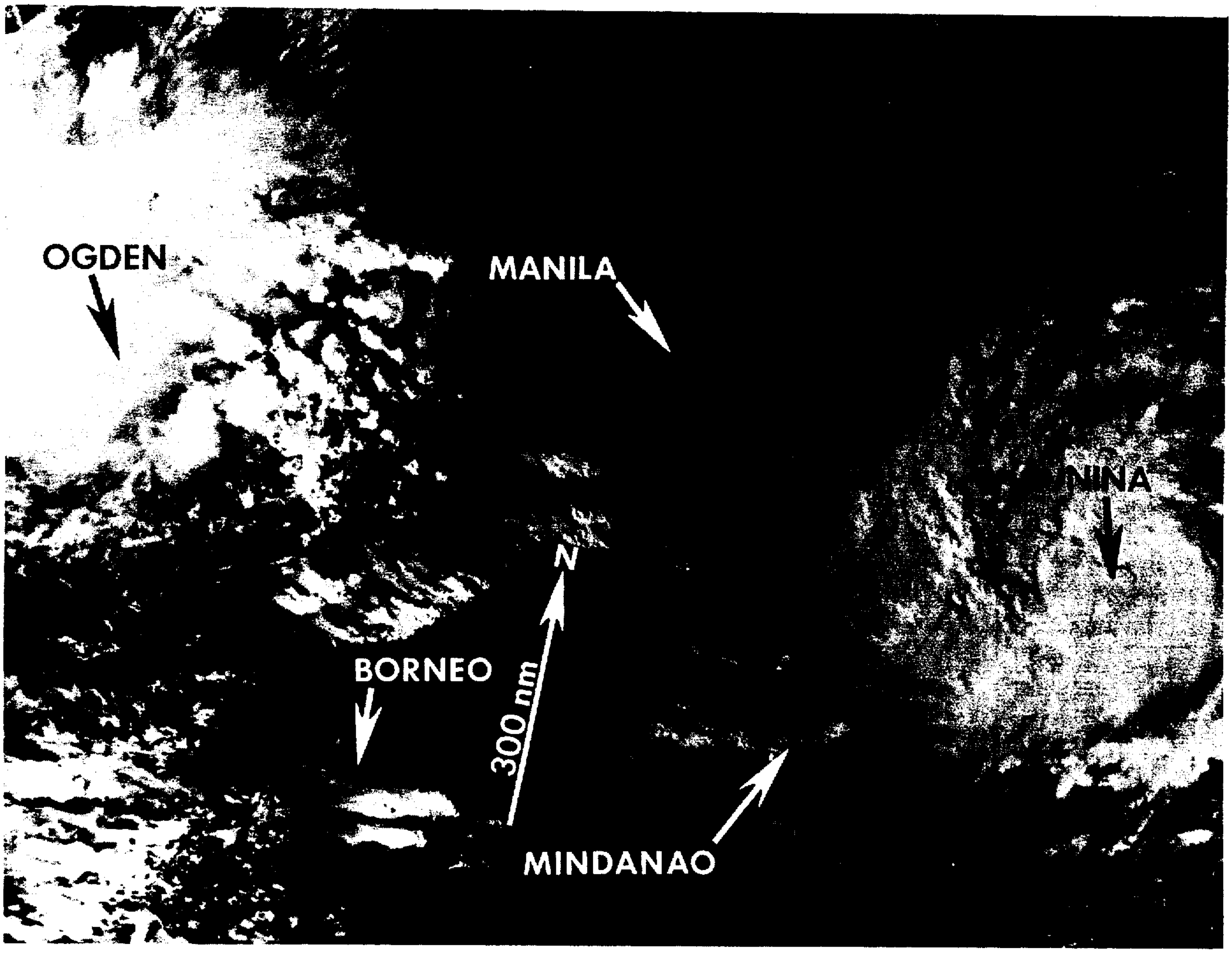
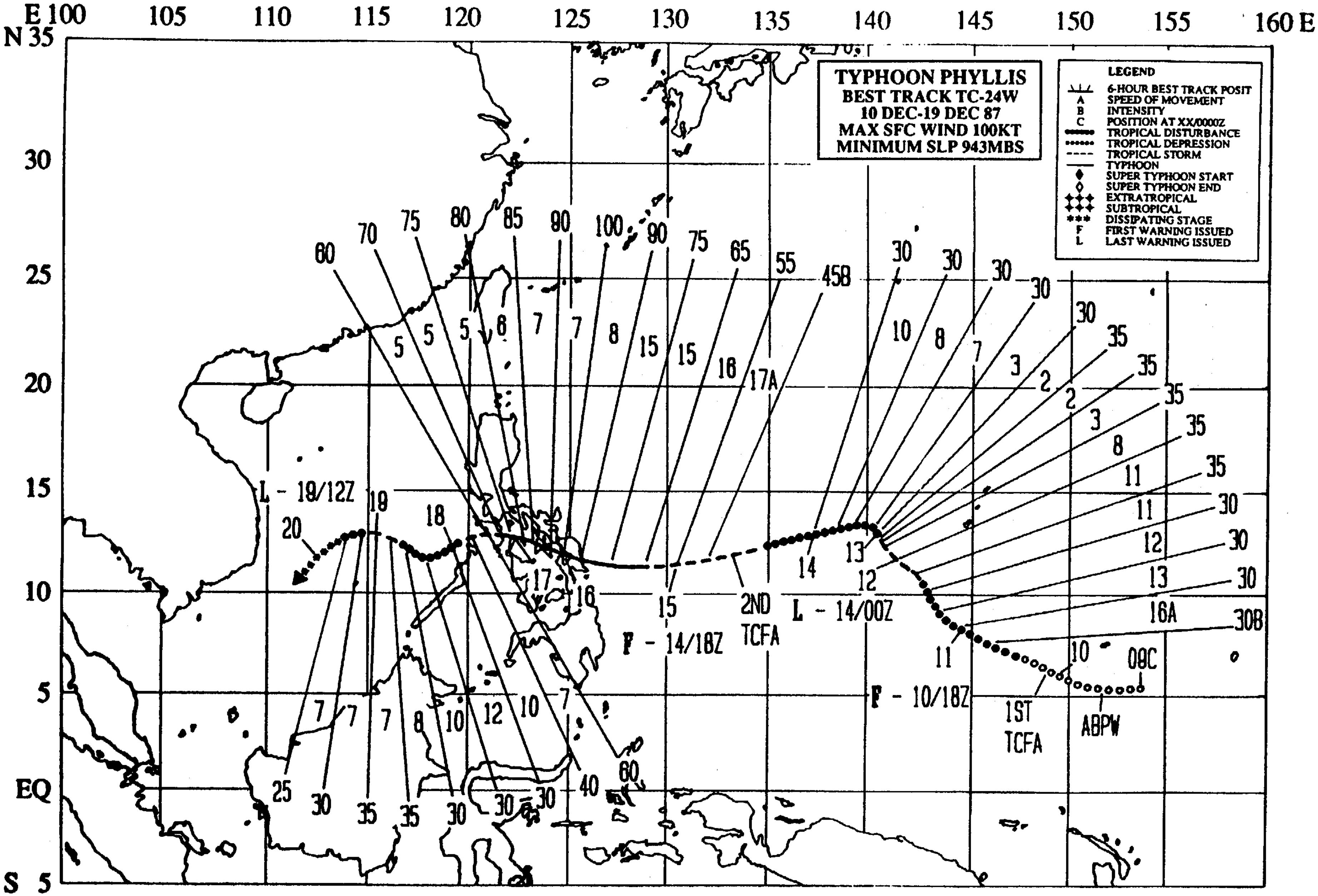


Figure 3-23-1. The third significant tropical cyclone of November, Tropical Storm Ogden, developed into a tropical storm in the South China Sea and quickly made landfall over southern Vietnam. Ogden was first detected late on November 20th as a poorly organized area of convection just east of the Philippines. Once in the South China Sea, the development of spiralling low-level cloud lines led to the system's first mention on the Significant Tropical Weather Advisory (ABPW PGTW) at 230600Z. At 240400Z, a Tropical Cyclone Formation Alert (TCFA) was issued based on the improved low-level cloud organization and synoptic reports of a closed surface circulation with maximum winds of 15 to 25 kt (8 to 13 m/sec). Shortly thereafter, Dvorak intensity analysis of satellite imagery estimated 30 kt (15 m/sec) winds which prompted the first warning on Tropical Depression 23W at 240600Z (see image above). At 241800Z, Ogden reached a maximum intensity of 45 kt (23 m/sec) just prior to making landfall. Ogden made landfall on the east coast of Vietnam 18 nm (33 km) south of Tuy Hoa at 241900Z. The final warning was issued at 250000Z as the system moved inland and dissipated (240712Z November NOAA visual imagery).


TYPHOON PHYLLIS
BEST TRACK TC-24W
10 DEC-19 DEC 87
MAX SFC WIND 100KT
MINIMUM SLP 943MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 19/12Z
F - 14/18Z
2ND TCFA
L - 14/00Z
F - 10/18Z
1ST TCFA
ABPW

TROPICAL STORM PHYLLIS (24W)

Typhoon Phyllis was the only significant tropical cyclone to develop in the western North Pacific in December and the third to regenerate over water in 1987 (reference Tropical Storms Ed (12W) and Maury (21W)). It struck the central Philippine Islands three weeks after Super Typhoon Nina (22W) and added further misery to that ravaged nation.

Phyllis began as an area of weakly organized convection in the eastern Caroline Islands 150 nm (278 km) southeast of the Truk Atoll. It was mentioned for the first time on the 091030Z December Significant Tropical Weather Advisory (ABPW PGTW) after exhibiting a rapid increase in the amount and organization of convection. The potential development was listed as fair due to the pre-existence of a low-level circulation and unrestricted upper-level outflow.

A Tropical Cyclone Formation Alert (TCFA) was issued the next day at 100230Z when a satellite intensity estimate (Dvorak, 1984) indicated 25 kt (13 m/sec) winds at the surface. The first warning, on Tropical Depression 24W, came at 101800Z as the estimate of the surface winds increased to 30 kt (15 m/sec) and the associated deep convection became more centralized. At that time, Tropical

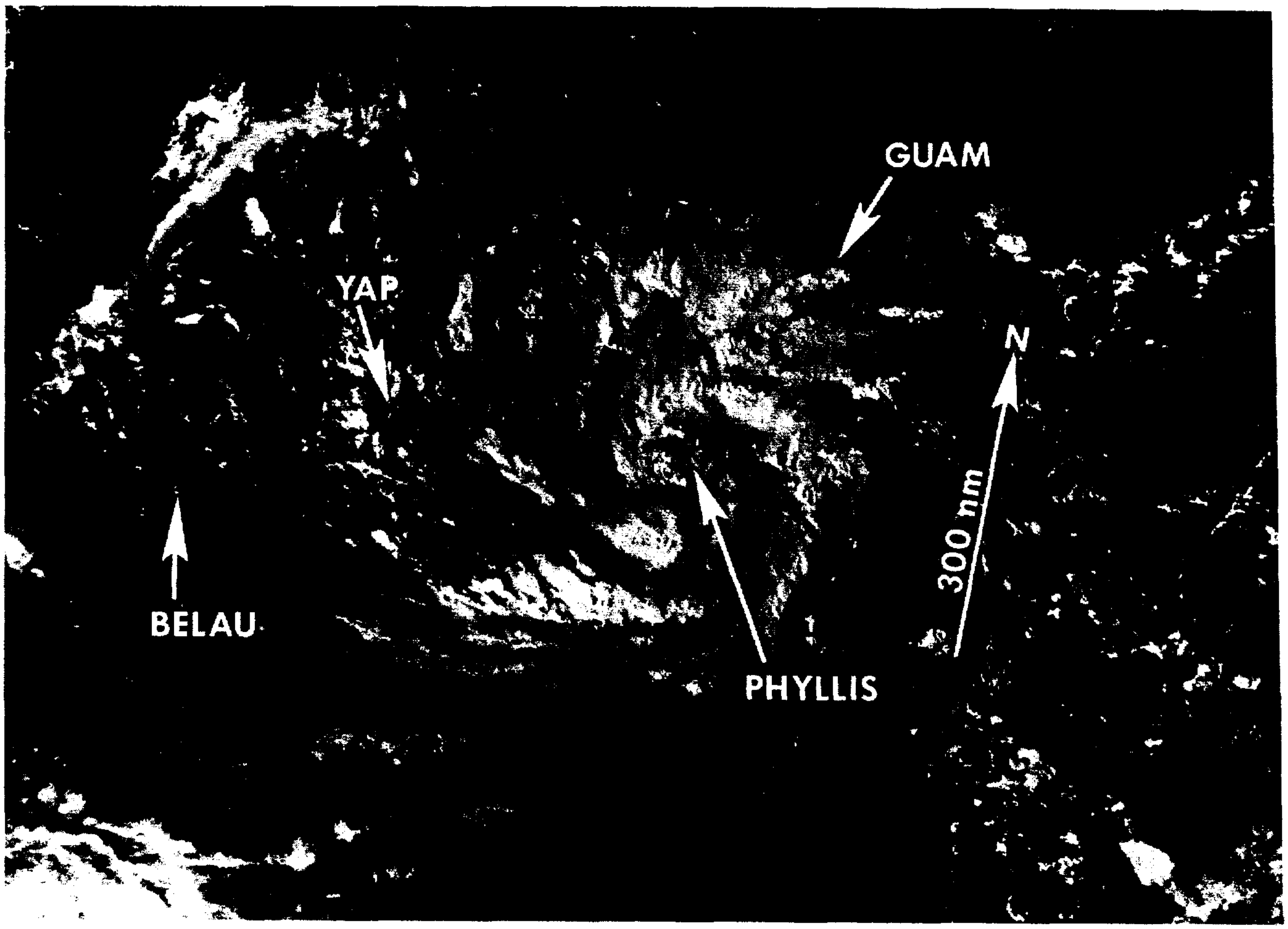


Figure 3-24-1. The well-defined, low-level circulation center of Tropical Depression 24W is revealed by the spiral convective bands of cloudiness (110547Z December NOAA visual imagery).

Depression 24W was located 370 nm (685 km) south-southeast of Guam and was moving toward the northwest. Twenty-four hours later, it made its closest point of approach to Guam (210 nm (389 km) to the southwest) and was upgraded to a tropical storm based on the development of a large cloud system and improved upper-level outflow in the southwest quadrant (see Figure 3-24-1). Early dissipation was forecast (beginning with the third warning at 110600Z). The approach of an eastward-moving, mid-latitude trough would increase the vertical wind shear. As the short wave moved eastward from mainland China, Phyllis slowed its forward motion until 130600Z, then abruptly changed course and accelerated toward the west-southwest. After downgrading the tropical cyclone to a tropical depression at 130000Z, the final warning followed at 140000Z. The displacement of central convection to the northeast of the low-level circulation center and the entrainment of cooler, drier air appeared to have started an irreversible weakening process.

However, within 18-hours (once the vertical wind shear decreased), Phyllis began to reestablish its central convection under a favorable upper-level outflow pattern. This

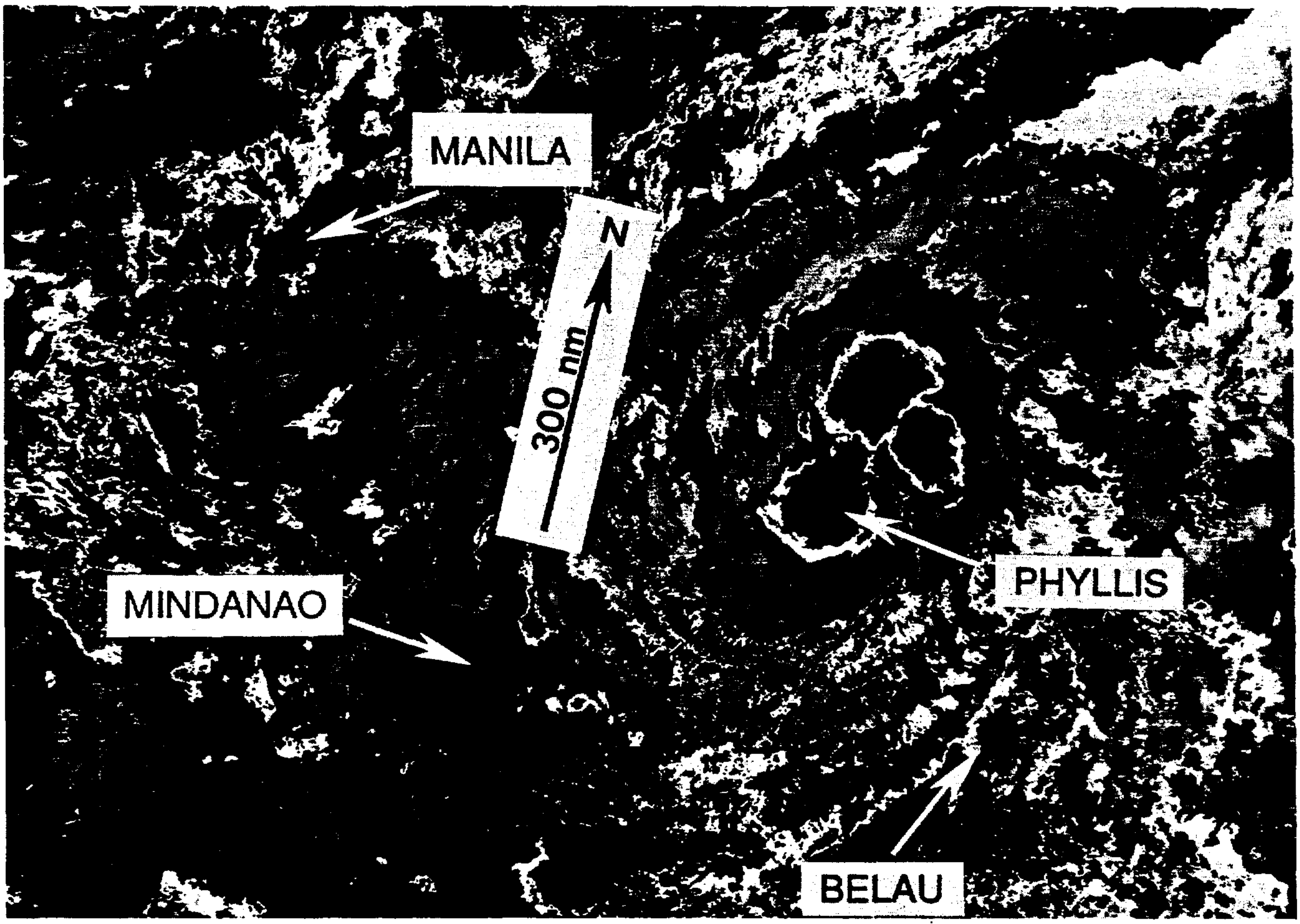


Figure 3-24-2. Tropical Storm Phyllis shortly after regeneration (142136Z December DMSP infrared imagery).

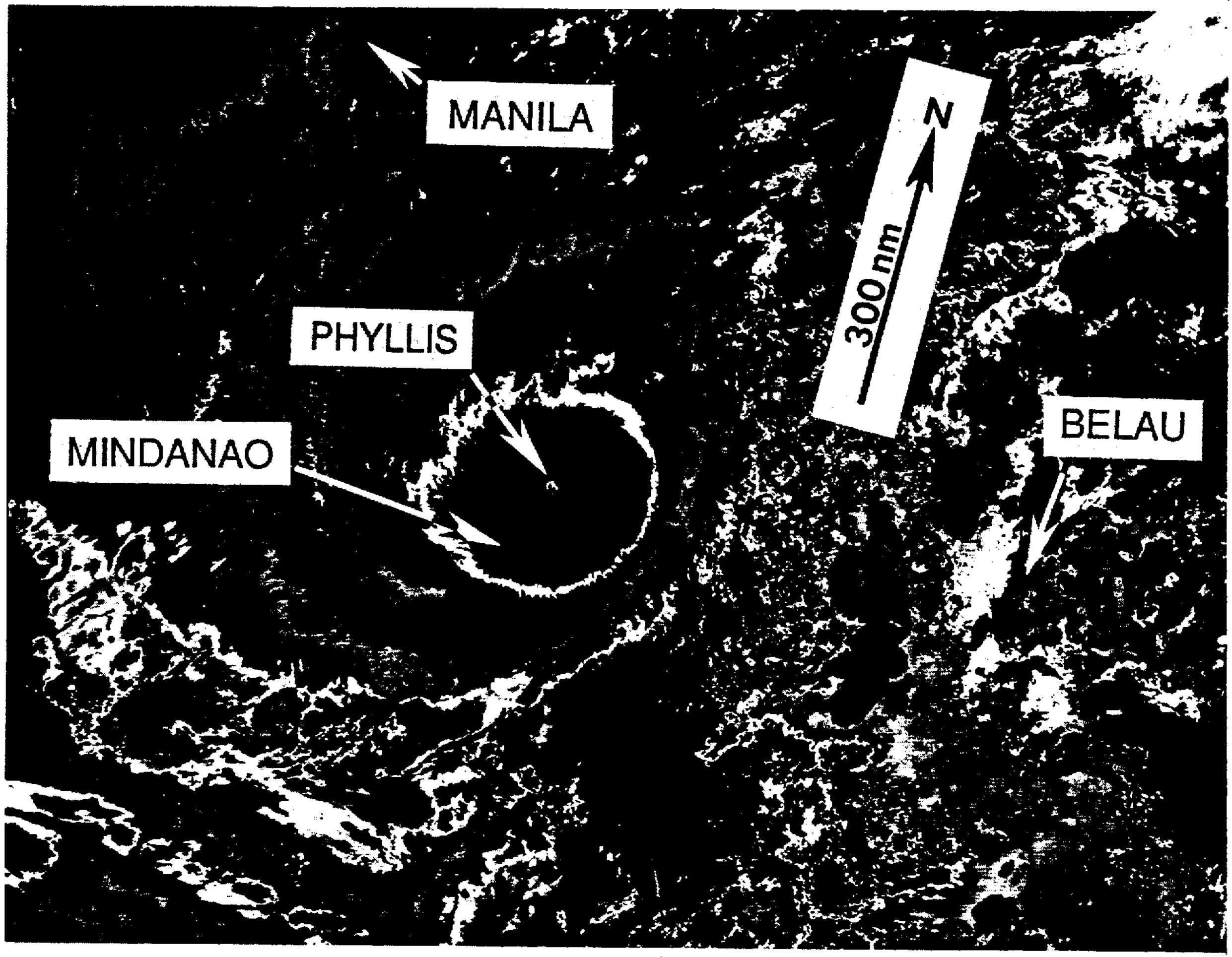


Figure 3-24-3. Tightly wrapped, small eye of Typhoon Phyllis during landfall on the island of Samar (152123Z December DMSP infrared imagery).

resulted in the issuance of a second TCFA at 141630Z. The (first regenerated) warning followed at 141800Z (as warning number 15 on the system) based on the satellite intensity estimate of 45 kt (23 m/sec) (see Figure 3-24-2). Intensification continued until 150000Z when Phyllis peaked at 100 kt (51 m/sec) while making landfall on the island of Samar in the central Philippine Islands (Figure 3-24-3). Phyllis left ten people dead and thirteen more were listed as missing when a ferry boat sank off of northern Samar.

After peaking, Phyllis weakened slowly for 24-hours while traversing the central Philippine Islands. Weakened by the frictional effects of the surrounding mountainous island terrain, Phyllis entered the South China Sea and was downgraded to a tropical depression at 180000Z. The forecast to dissipate within 48-hours over water was basically correct, however, the tropical cyclone did briefly reintensify to 35 kt (18 m/sec) on the 19th. No other reports of deaths or serious damage were received.

3. NORTH INDIAN OCEAN TROPICAL CYCLONES

Eight significant tropical cyclones developed in the North Indian Ocean during 1987. That set a new all-time record and surpassed the previous high of seven systems in 1979. This was in sharp contrast with 1986 when only three significant tropical cyclones were observed. The long-term mean is approximately four per year. These eight systems (all of tropical storm intensity) developed during the Spring and Fall transition periods (i. e., the intervals of weak opposing wind flow between the Northeast and Southwest Monsoons). Tables 3-5 and 3-6 provide a summary of information for 1987 and comparison with earlier years.

TABLE 3.5 NORTH INDIAN OCEAN
1987 SIGNIFICANT TROPICAL CYCLONES

TROPICAL CYCLONE	PERIOD OF WARNING	CALENDAR DAYS OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/S)	ESTIMATED MSLP - MB
TC 01B	01 FEB - 03 FEB	3	11	55 (28)	984
TC 02B	02 JUN - 05 JUN	4	12	55 (28)	983
TC 03A	05 JUN - 09 JUN	5	18	50 (26)	987
TC 04B	15 OCT - 16 OCT	2	3	45 (23)	991
TC 05B	31 OCT - 03 NOV	4	14	40 (21)	994
TC 06B	11 NOV - 13 NOV	3	6	50 (26)	987
TC 07A	08 DEC - 11 DEC	4	14	45 (23)	991
TC 08B	18 DEC - 19 DEC	2	5	35 (18)	997
	1987 TOTALS:	26*	83		

*Overlapping days are counted only once in sum.

TABLE 3-6. FREQUENCY OF NORTH INDIAN OCEAN TROPICAL CYCLONES

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1971*	-	-	-	-	-	0	0	0	0	1	1	0	2
1972*	0	0	0	1	0	0	0	0	2	0	1	0	4
1973*	0	0	0	0	0	0	0	0	0	1	2	1	4
1974*	0	0	0	0	0	0	0	0	0	0	1	0	1
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
1977	0	0	0	0	1	1	0	0	0	1	2	0	5
1978	0	0	0	0	1	0	0	0	0	1	2	0	4
1979	0	0	0	0	1	1	0	0	2	1	2	0	7
1980	0	0	0	0	0	0	0	0	0	0	1	1	2
1981	0	0	0	0	0	0	0	0	0	1	1	1	3
1982	0	0	0	0	1	1	0	0	0	2	1	0	5
1983	0	0	0	0	0	0	0	1	0	1	1	0	3
1984	0	0	0	0	1	0	0	0	0	1	2	0	4
1985	0	0	0	0	2	0	0	0	0	2	1	1	6
1986	1	0	0	0	0	0	0	0	0	0	2	0	3
1987	0	1	0	0	0	2	0	0	0	1	2	2	8
(1975-1987) AVERAGE	0.2	0.1	0.0	0.1	0.7	0.5	0.0	0.1	0.2	1.0	1.5	0.5	4.7
CASES	2	1	0	1	9	6	0	1	3	13	19	6	61

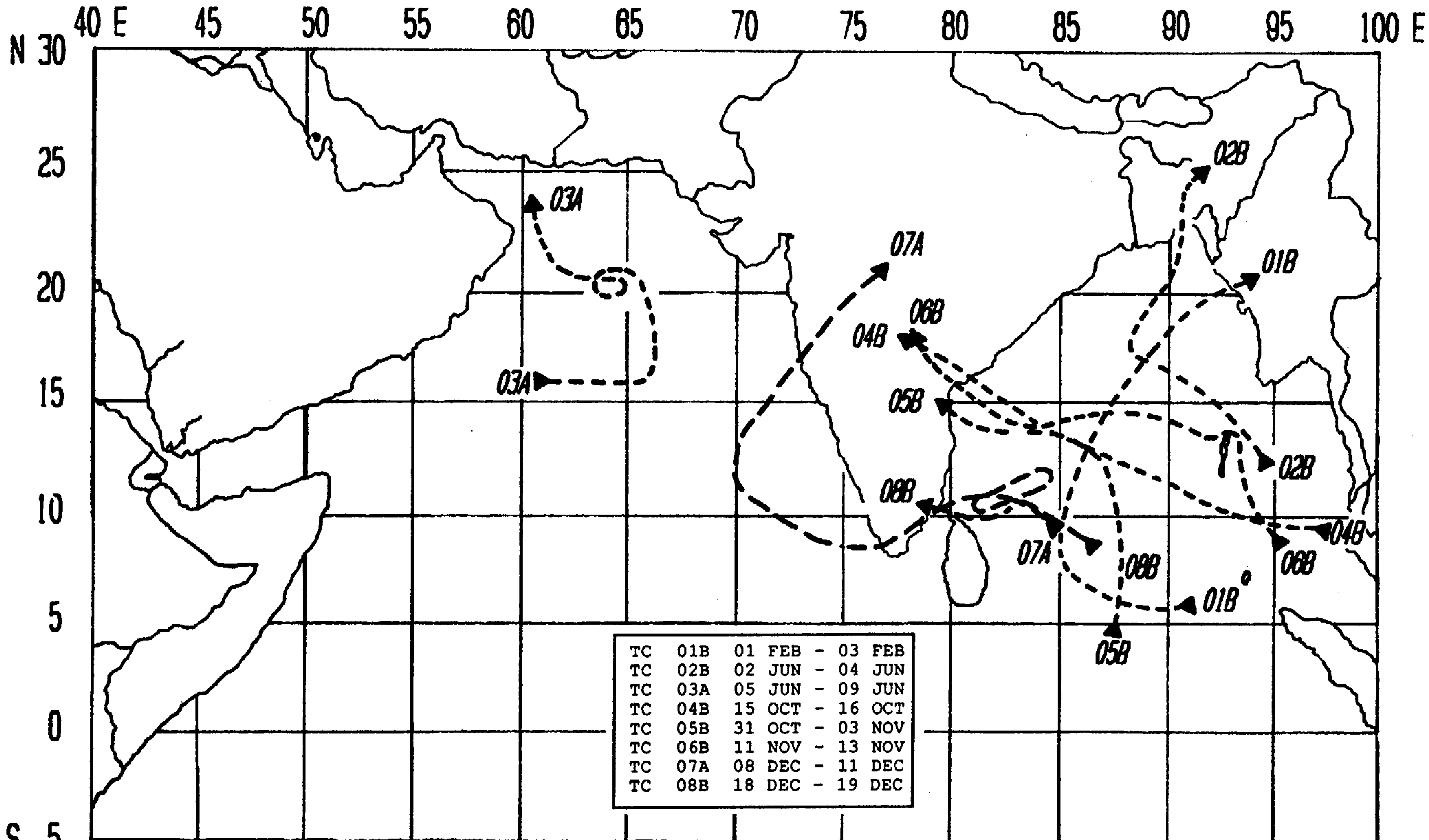
* JTWC WARNING RESPONSIBILITY BEGAN ON 4 JUN 71 FOR THE BAY OF BENGAL, EAST OF 90 DEGREES EAST LONGITUDE. AS DIRECTED BY CINCPAC, JTWC ISSUED WARNINGS ONLY FOR THOSE TROPICAL CYCLONES THAT DEVELOPED OR TRACKED THROUGH THAT PORTION OF THE BAY OF BENGAL. COMMENCING WITH THE 1975 TROPICAL CYCLONE SEASON, JTWC'S AREA OF RESPONSIBILITY WAS EXTENDED WESTWARD TO INCLUDE THE WESTERN PORTION OF THE BAY OF BENGAL AND THE ENTIRE ARABIAN SEA.

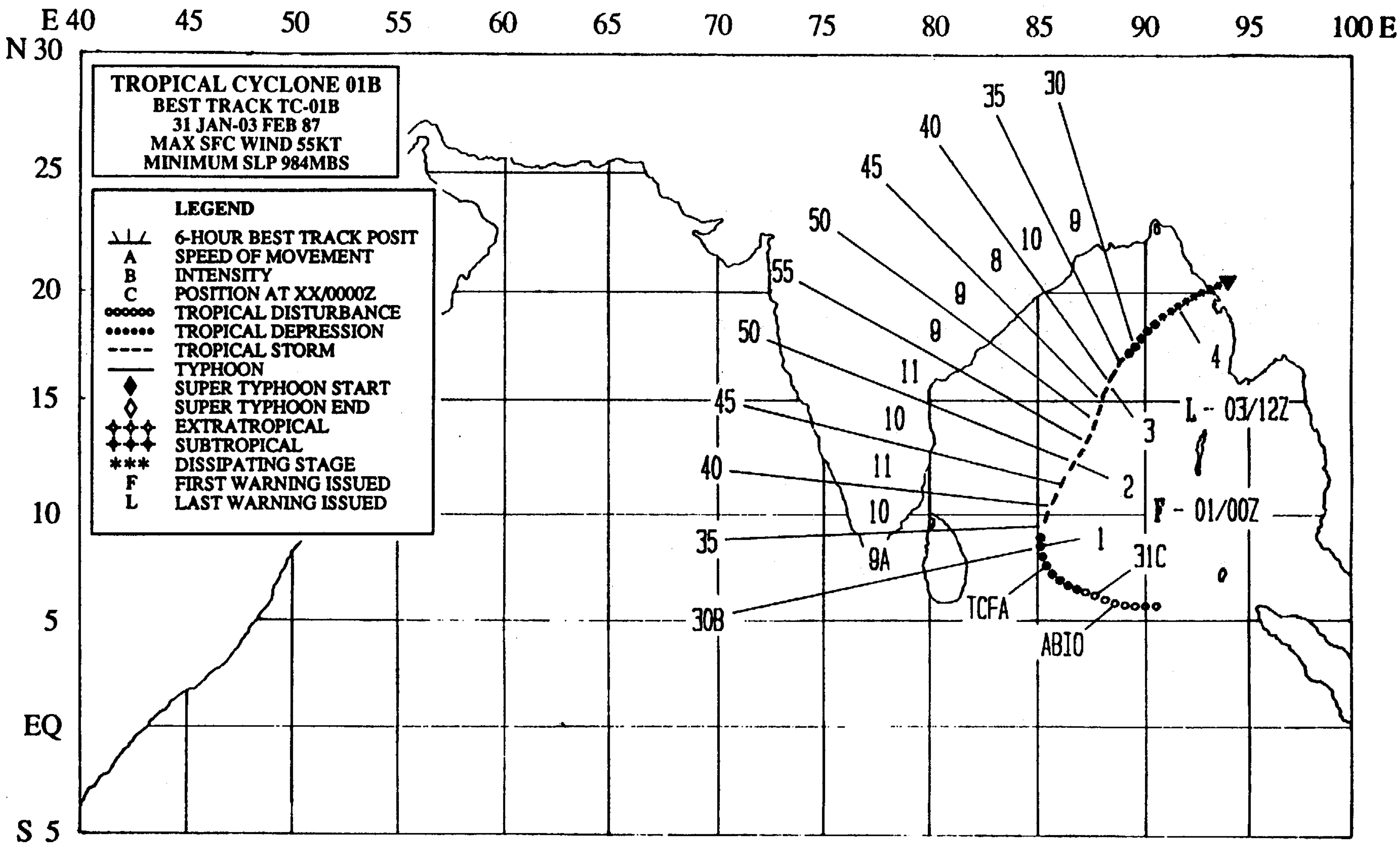
FORMATION ALERTS: 7 OF 8 FORMATION ALERTS DEVELOPED INTO SIGNIFICANT TROPICAL CYCLONES. TROPICAL CYCLONE FORMATION ALERTS WERE ISSUED FOR ALL OF THE SIGNIFICANT TROPICAL CYCLONES THAT DEVELOPED IN 1987, EXCEPT TROPICAL CYCLONE 03A.

WARNINGS: NUMBER OF CALENDAR WARNING DAYS: 26

NUMBER OF CALENDAR WARNING DAYS WITH TWO TROPICAL CYCLONES: 1

NUMBER OF CALENDAR WARNING DAYS WITH THREE TROPICAL CYCLONES: 0


40 E
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
0
S 5
03A
03A
07A
07A
06B
06B
04B
04B
05B
05B
02B
02B
01B
01B
08B
08B
TC 01B 01 FEB - 03 FEB
TC 02B 02 JUN - 04 JUN
TC 03A 05 JUN - 09 JUN
TC 04B 15 OCT - 16 OCT
TC 05B 31 OCT - 03 NOV
TC 06B 11 NOV - 13 NOV
TC 07A 08 DEC - 11 DEC
TC 08B 18 DEC - 19 DEC


TROPICAL CYCLONE 01B
BEST TRACK TC-01B
31 JAN-03 FEB 87
MAX SFC WIND 55KT
MINIMUM SLP 984MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5
L - 03/12Z
F - 01/00Z
TCFA
ABIO
30B
9A
31C

TROPICAL CYCLONE 01B

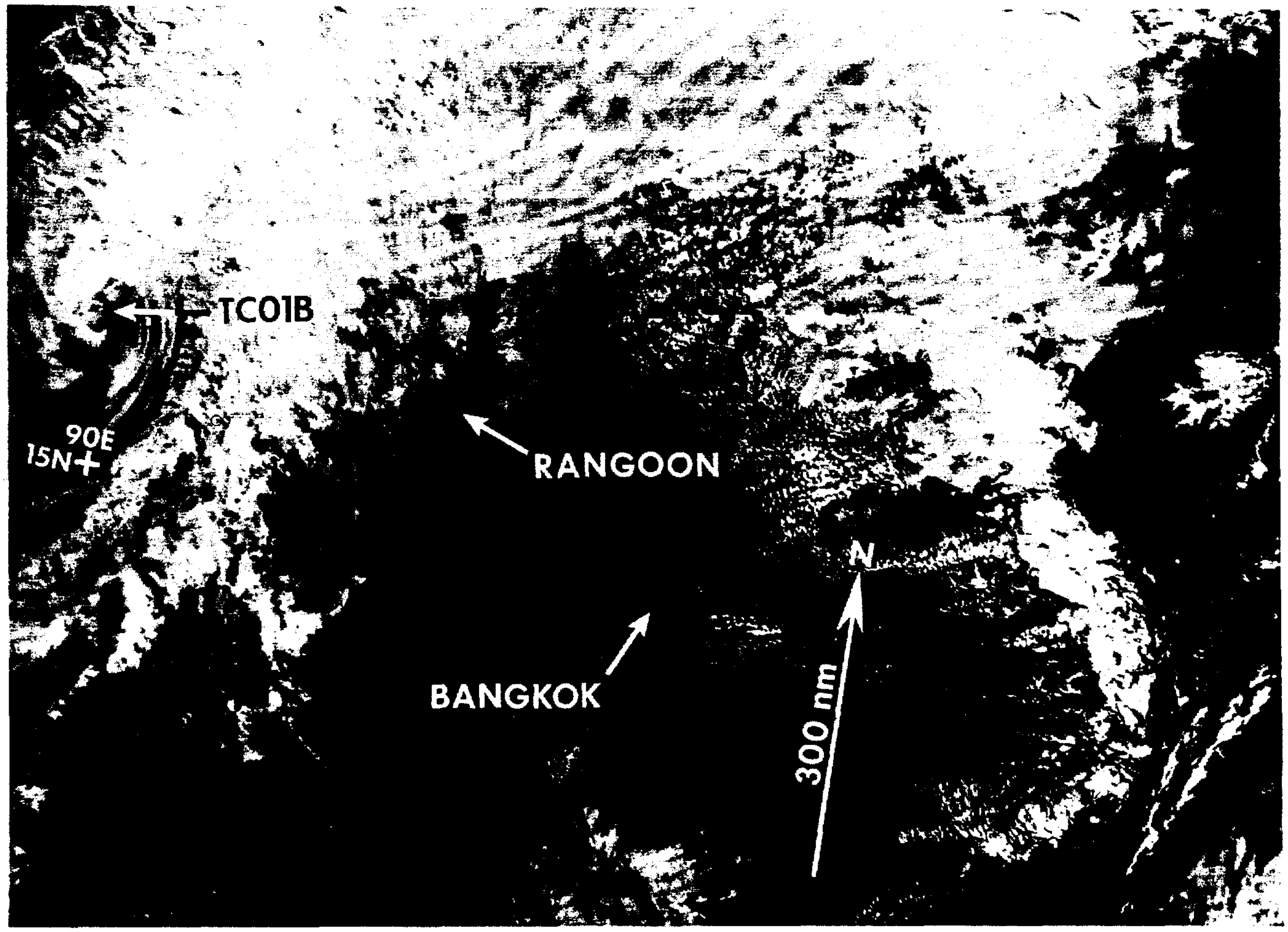
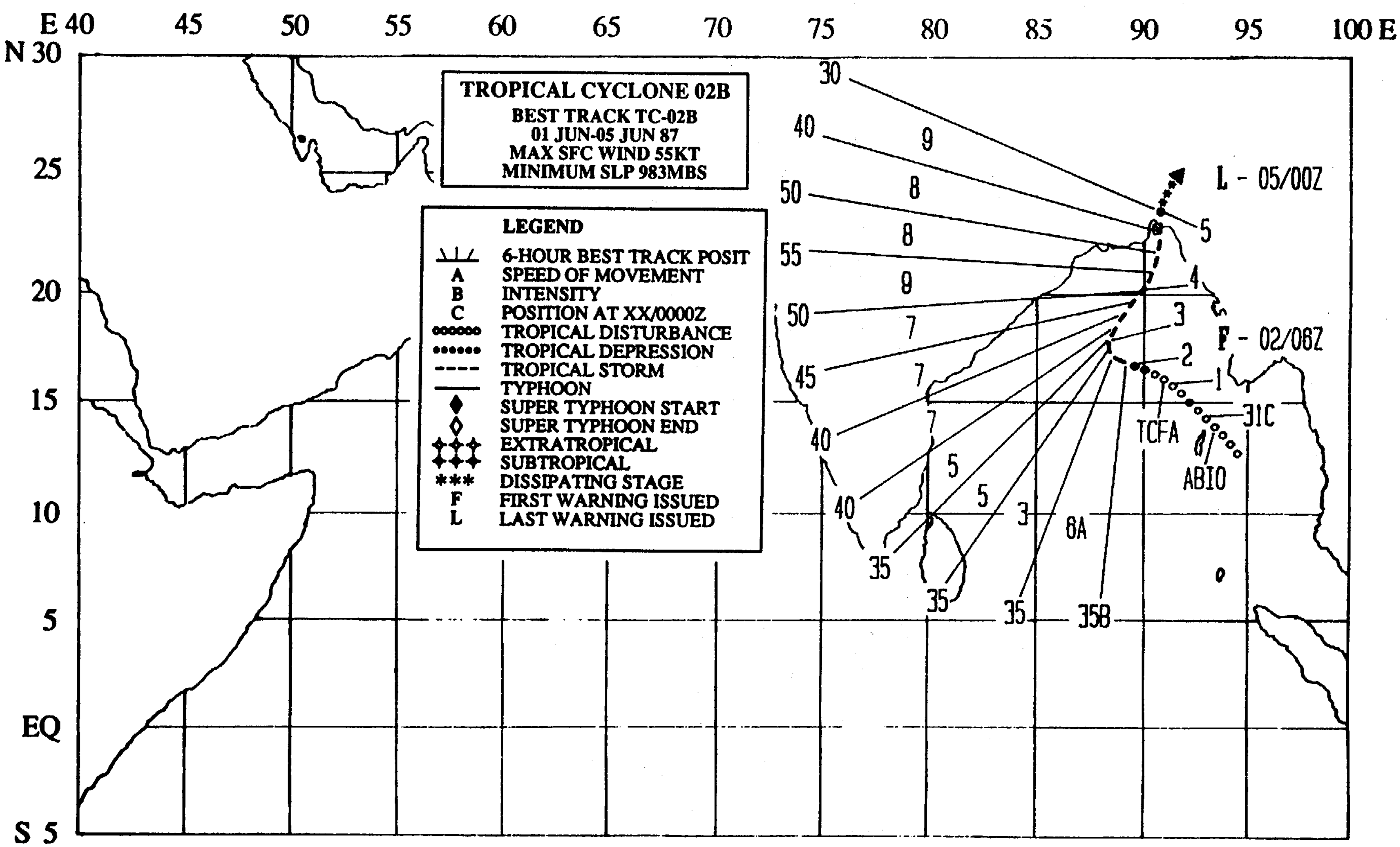


Figure 3-01B-1. Tropical Cyclone 01B was the first significant tropical cyclone to form in the Bay of Bengal during 1987. It was detected as an amorphous area of convection about 500 nm (926 km) east of Sri Lanka on the 29th of January and was noted on the 301800Z Significant Tropical Weather Advisory (ABIO PGTW). Satellite imagery at that time showed upper-level anticyclonically curved outflow over a weak, low-level circulation. Within the next 24-hours, the organization and amount of convection steadily increased. A Tropical Cyclone Formation Alert was issued at 311900Z. Satellite imagery showed convective banding had continued to increase, but sparse synoptic data showed no low surface pressures. At 0000Z on February 1st, the first warning was issued with the appearance of a central dense overcast and unrestricted outflow in all quadrants. The system then tracked steadily northeastward. The intensity peaked at 55 kt (28 m/sec) at 020600Z as the system began interaction with upper-level southwesterlies, which sent a long plume of cirrus northeastward across Burma. A partially exposed low-level circulation center became apparent at 030000Z, as increased vertical wind shear from the southwesterlies aloft stripped away the central cloudiness. Six hours later the low-level vortex was fully exposed (see above imagery). At 031200Z, JTWC issued the final warning on the 30 kt (15 m/sec) weakening tropical cyclone. The remnants of Tropical Cyclone 01B continued to track toward the northeast and dissipation occurred after it made landfall on February 4th over the northwest coast of Burma (030805Z February NOAA visual imagery).


TROPICAL CYCLONE 02B
BEST TRACK TC-02B
01 JUN-05 JUN 87
MAX SFC WIND 55KT
MINIMUM SLP 983MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 05/00Z
F - 02/06Z
TCFA
ABIO
31C
8A
35B
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5

TROPICAL CYCLONE 02B

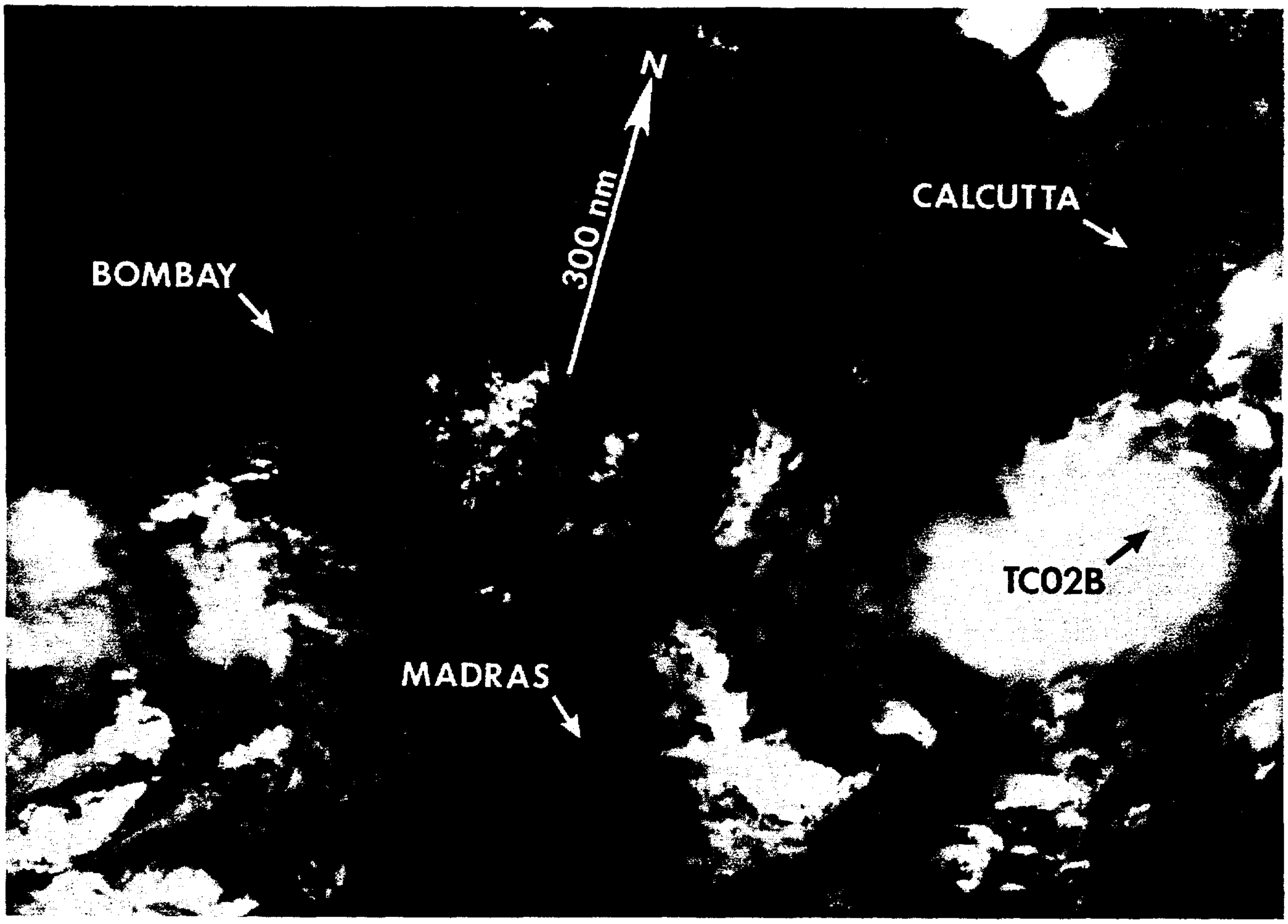
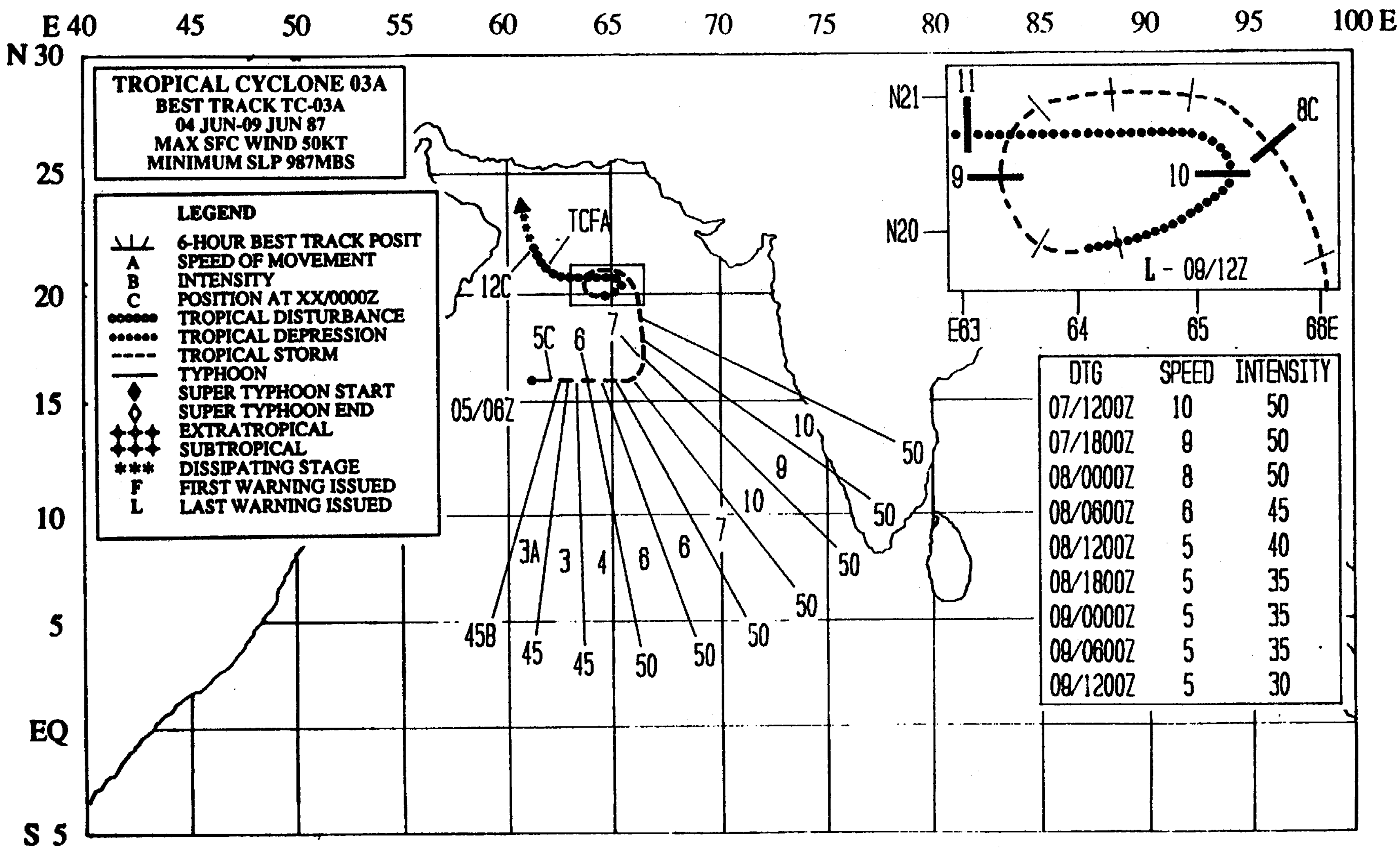


Figure 3-02B-1. Tropical Cyclone 02B was the second significant tropical cyclone to form in the Bay of Bengal. It was detected on satellite imagery as an area of organizing convection about 220 nm (407 km) southwest of Rangoon, Burma and was first mentioned as a new suspect area on the 301800Z May Significant Tropical Weather Advisory (ABIO PGTW). The development of strong central convection prompted a Tropical Cyclone Formation Alert on June 1st at 0600Z. The first tropical cyclone warning followed a day later at 020600Z as a result of continued development. The forecast track toward the northwest, which agreed closely with the Half Persistence and Climatology (HPAC) guidance, changed during the subsequent 24-hours, as mid-level ridging caused Tropical Cyclone 02B to assume a recurvature track toward the northeast (see above imagery). The One-Way Interactive Tropical Cyclone Model (OTCM), correctly predicted this recurvature toward the northeast; however, the guidance was discounted due to the previous poor performance of the model in this region. At 040600Z, Tropical Cyclone 02B reached its maximum intensity of 55 kt (28 m/sec) and developed a ragged eye. This intensity was maintained until the system made landfall over Bangladesh at 041200Z. Rapid dissipation followed. No reports of damage or loss of life were received (030421Z June DMSP visual imagery).


TROPICAL CYCLONE 03A
BEST TRACK TC-03A
04 JUN-09 JUN 87
MAX SFC WIND 50KT
MINIMUM SLP 987MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
TCFA
12C
05/06Z
L - 08/12Z
DTG SPEED INTENSITY
07/1200Z 10 50
07/1800Z 9 50
08/0000Z 8 50
08/0600Z 6 45
08/1200Z 5 40
08/1800Z 5 35
09/0000Z 5 35
09/0600Z 5 35
09/1200Z 5 30

TROPICAL CYCLONE 03A

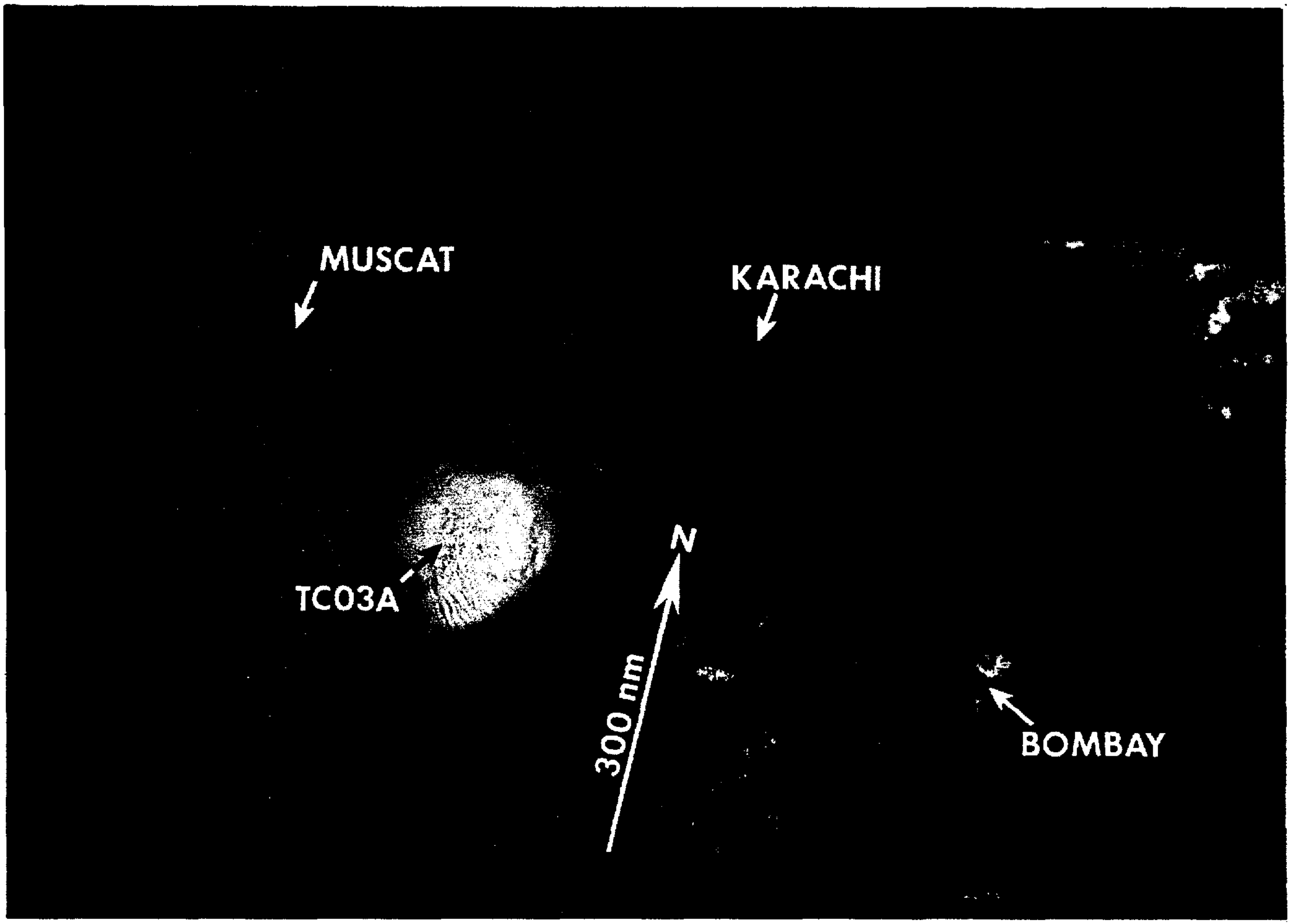
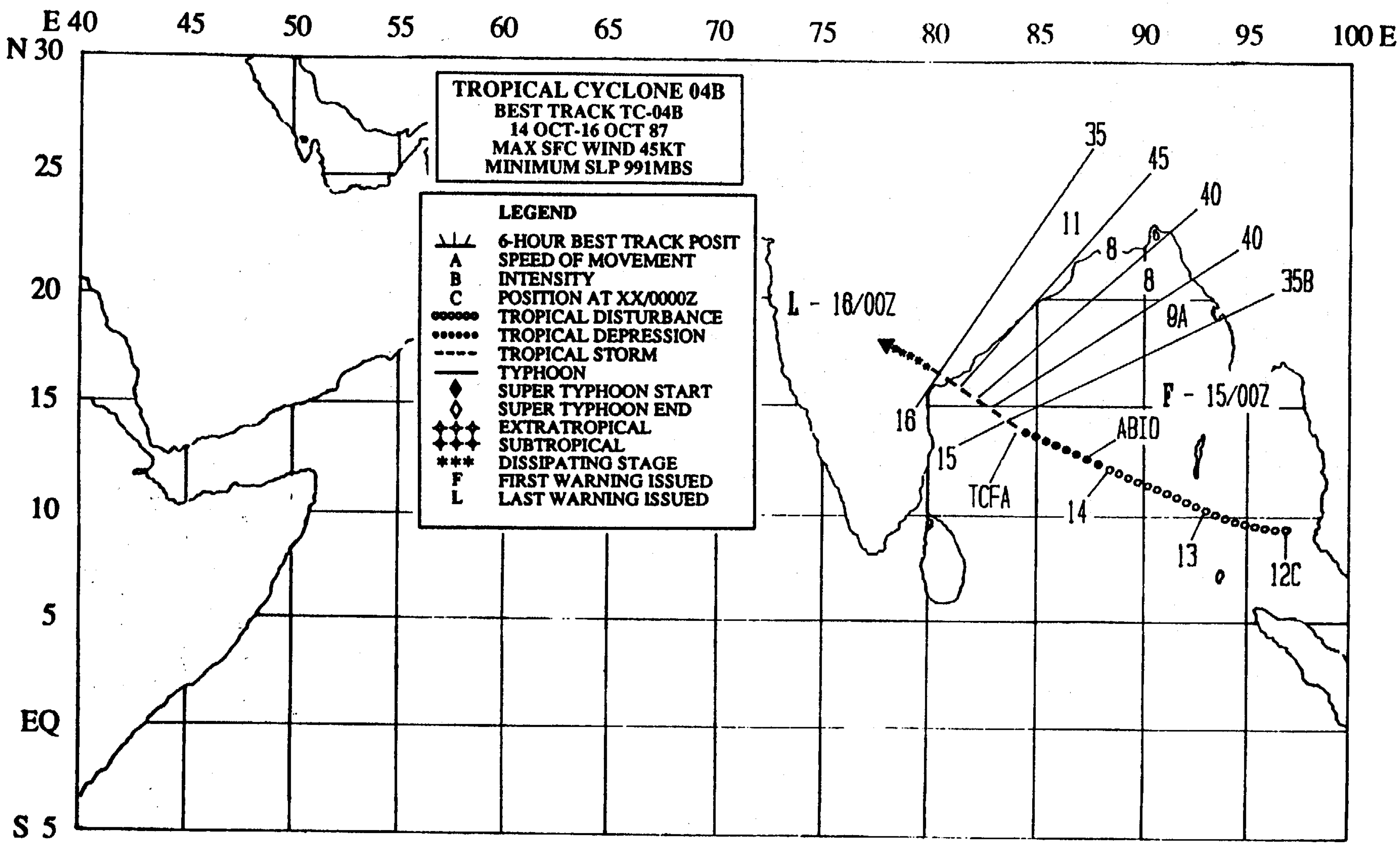


Figure 3-03A-1. Tropical Cyclone 03A began on June 4th as a monsoon depression with the supporting convection displaced from the low-level circulation center. Throughout the life of Tropical Cyclone 03A, brisk southwesterly flow dominated the low-levels with an overlying tropical easterly jet in the upper-levels. The low pressure center developed 250 nm (463 km) southeast of central Oman and moved slowly eastward along the edge of the low-level southwesterlies. An expanded radius of over 30 kt (15 m/sec) winds in the south semicircle resulted from interaction between the tropical cyclone and the already brisk monsoonal flow. JTWC issued its first warning at 050600Z without a preceding Tropical Cyclone Formation Alert, due to the rapid consolidation of convection around an exposed low-level circulation center. Post-analysis indicated the system had actually reached tropical storm intensity 18-hours earlier. Tropical Cyclone 03A reached a maximum intensity of 50 kt (26 m/sec) at 060000Z shortly before it abruptly changed its track toward the north. This intensity was maintained until 080000Z when the track became westerly. The final warning was issued at 091200Z as the system rapidly weakened due to increased vertical wind shear. Cloudiness associated with the remains of the low-level circulation flared up for a short time between 110400Z (see above imagery) and 111200Z; however, complete dissipation over water occurred within the next 24-hours (110501Z June DMSP visual imagery).


TROPICAL CYCLONE 04B
BEST TRACK TC-04B
14 OCT-16 OCT 87
MAX SFC WIND 45KT
MINIMUM SLP 991MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L - 16/00Z
F - 15/00Z
ABIO
TCFA
35
45
40
40
35B
11
8
8
9A
16
15
14
13
12C
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5

TROPICAL CYCLONE 04B

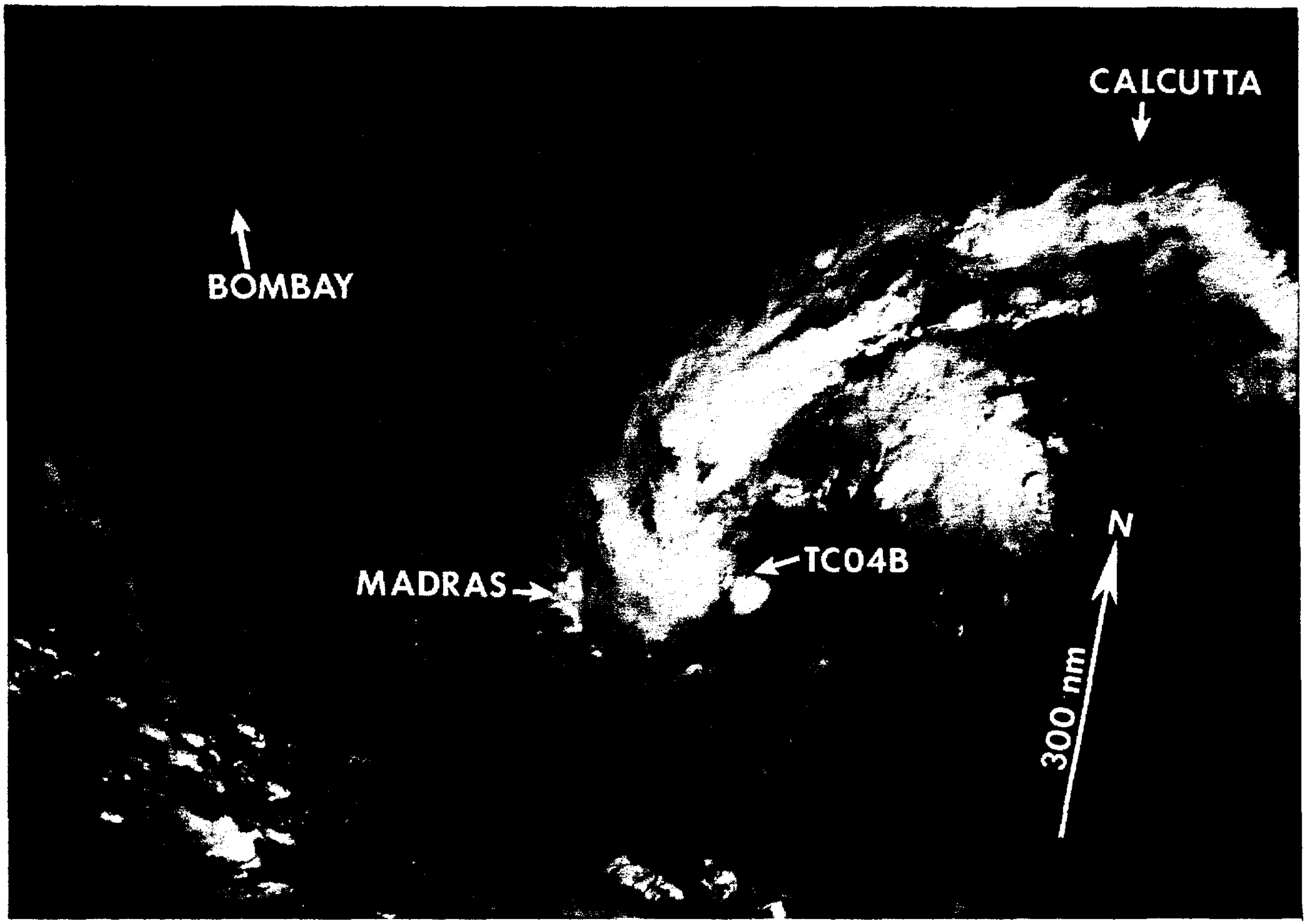
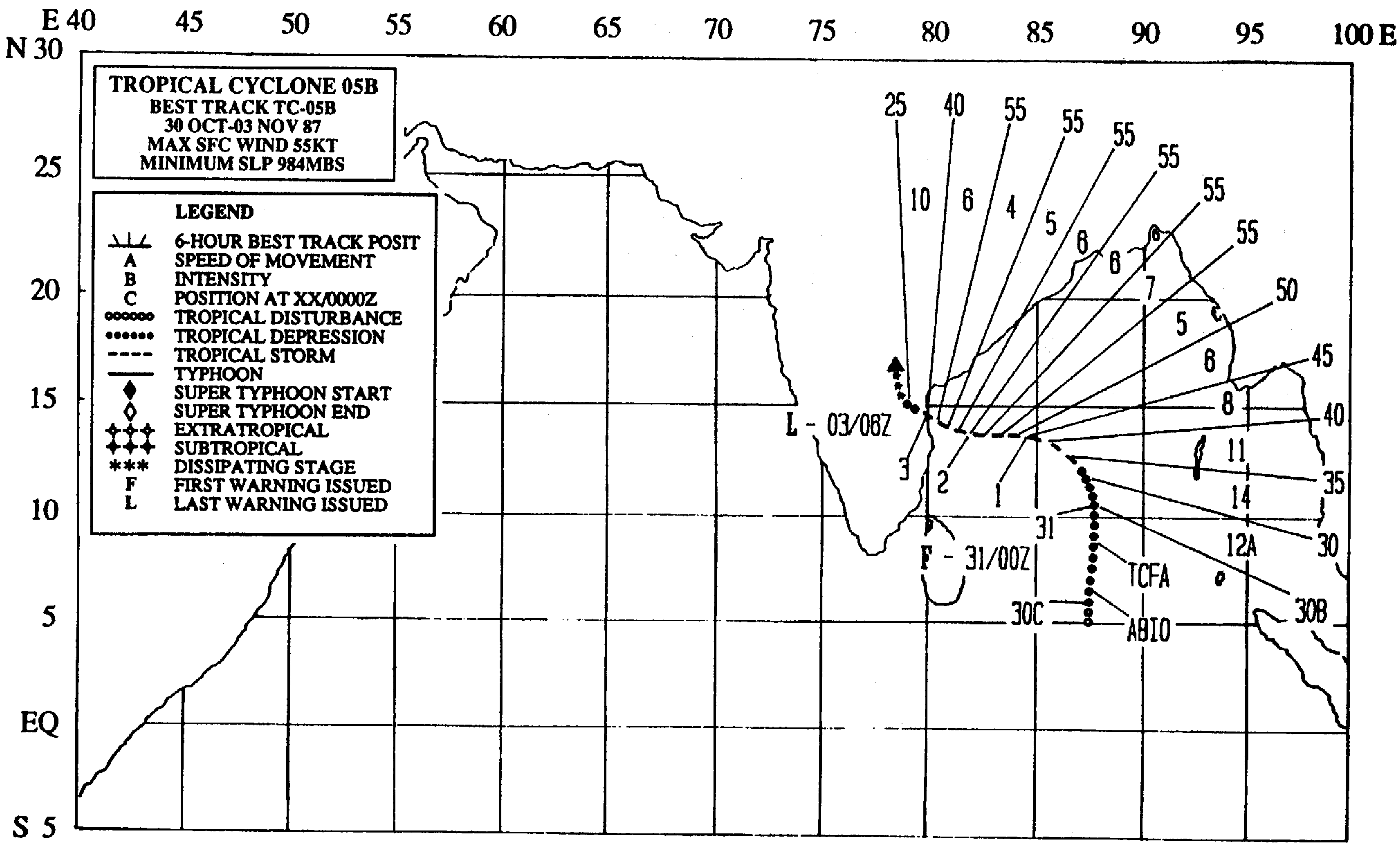


Figure 3-04B-1. Tropical Cyclone 04B began as a monsoon depression in the Andaman Sea on the 12th of October and tracked toward the west-northwest. By 13 October at 0600Z, the cloud system had separated from the general monsoonal cloudiness. At that time, JTWC added the system to its Significant Tropical Weather Advisory (ABIO PGTW), and indicated its potential for continued development was fair. At 142030Z, JTWC issued a Tropical Cyclone Formation Alert based on the appearance of a central dense overcast and an associated higher Dvorak intensity estimate of 30 kt (15 m/sec). The first warning followed at 150000Z as a result of a Dvorak estimate of 35 kt (18 m/sec) surface winds (see above imagery). This first warning, which indicated landfall within the next 12- to 24-hours, was also designated as the final warning. However, this forecast proved to be overly optimistic. At 151800Z, Tropical Cyclone 04B peaked at 45 kt (23 m/sec) and a second warning was issued. This was necessary because Tropical Cyclone 04B was on track, but still over water. At 160000Z, Tropical Cyclone 04B was finalled for a second time as it moved inland and weakened (150408Z October DMSP visual imagery).


TROPICAL CYCLONE 05B
BEST TRACK TC-05B
30 OCT-03 NOV 87
MAX SFC WIND 55KT
MINIMUM SLP 984MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5
L - 03/06Z
F - 31/00Z
TCFA
ABIO
30C
30B
31
12A

TROPICAL CYCLONE 05B

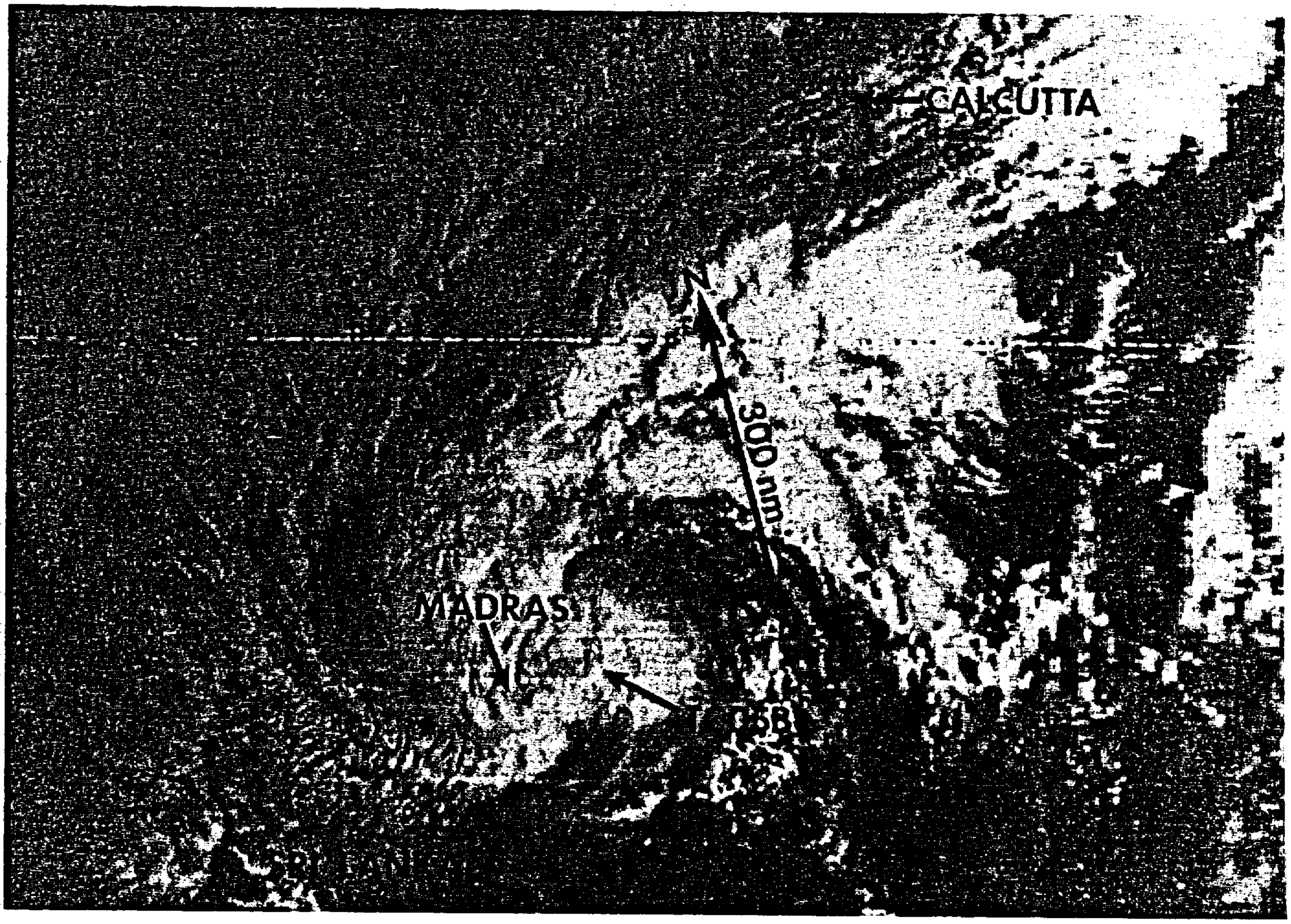
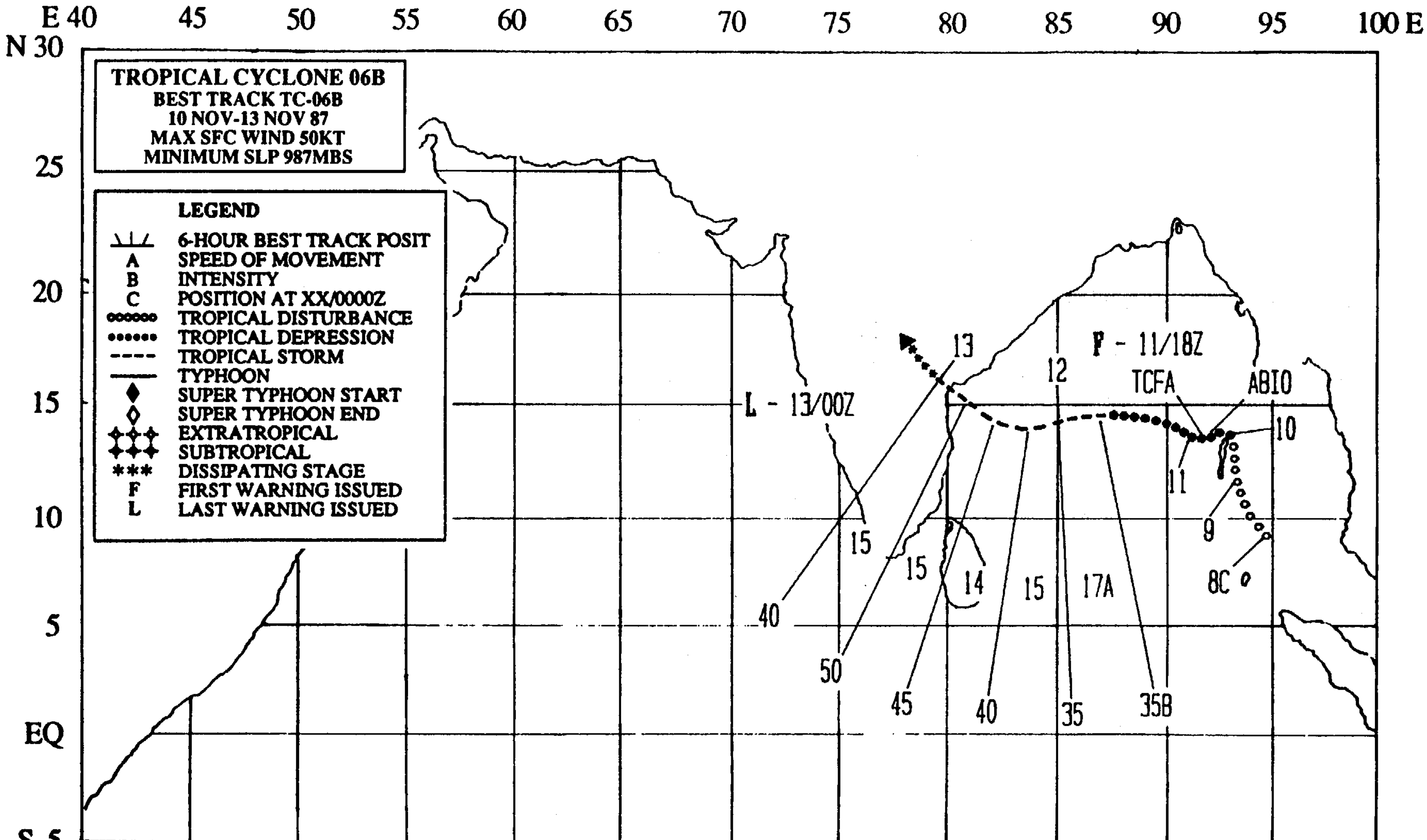


Figure 3-05B-1. Tropical Cyclone 05B spawned from the monsoon trough over the southern Bay of Bengal midway between Sri Lanka and northern Sumatra in late October. Its detection on satellite imagery resulted in the reissuance of the Significant Tropical Weather Advisory (ABIO PGTW) at 300300Z and assignment of a fair potential for development. Intensification continued and a Tropical Cyclone Formation Alert was issued at 301557Z. The first warning was issued at 310000Z. Tropical Cyclone 05B moved toward the north and was initially forecast to continue moving northward, then turn northeastward, crossing southern Bangladesh and northern Burma. Instead, it assumed a northwestward track and slowed in forward speed. Once the system began to take a definite track toward the northwest, the forecast philosophy was changed and the One-Way Tropical Cyclone Model (OTCM) guidance was followed with excellent results. The peak intensity of 55 kt (28 m/sec) was reached at 1200Z on the 1st of November and maintained until the system was close inshore as evidenced by the well-defined convective cloud band on the satellite image above. Issuance of the final warning occurred at 030600Z as Tropical Cyclone 05B was dissipating over land (020221Z November NOAA visual imagery).


TROPICAL CYCLONE 06B
BEST TRACK TC-06B
10 NOV-13 NOV 87
MAX SFC WIND 50KT
MINIMUM SLP 987MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5
F - 11/18Z
L - 13/00Z
TCFA
ABIO
13
12
11
10
9
8C
15
15
14
15
17A
40
50
45
40
35
35B

TROPICAL CYCLONE 06B

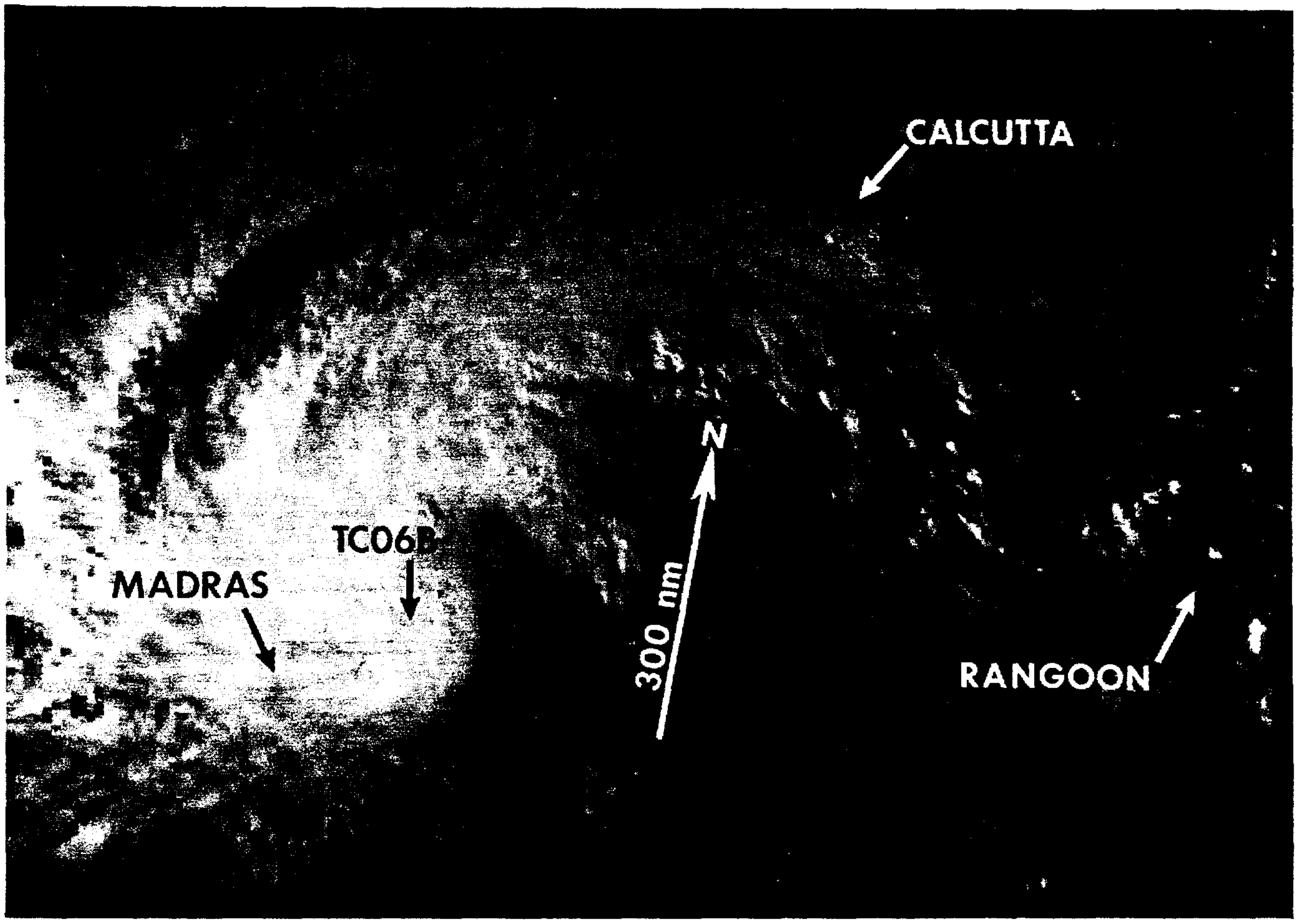
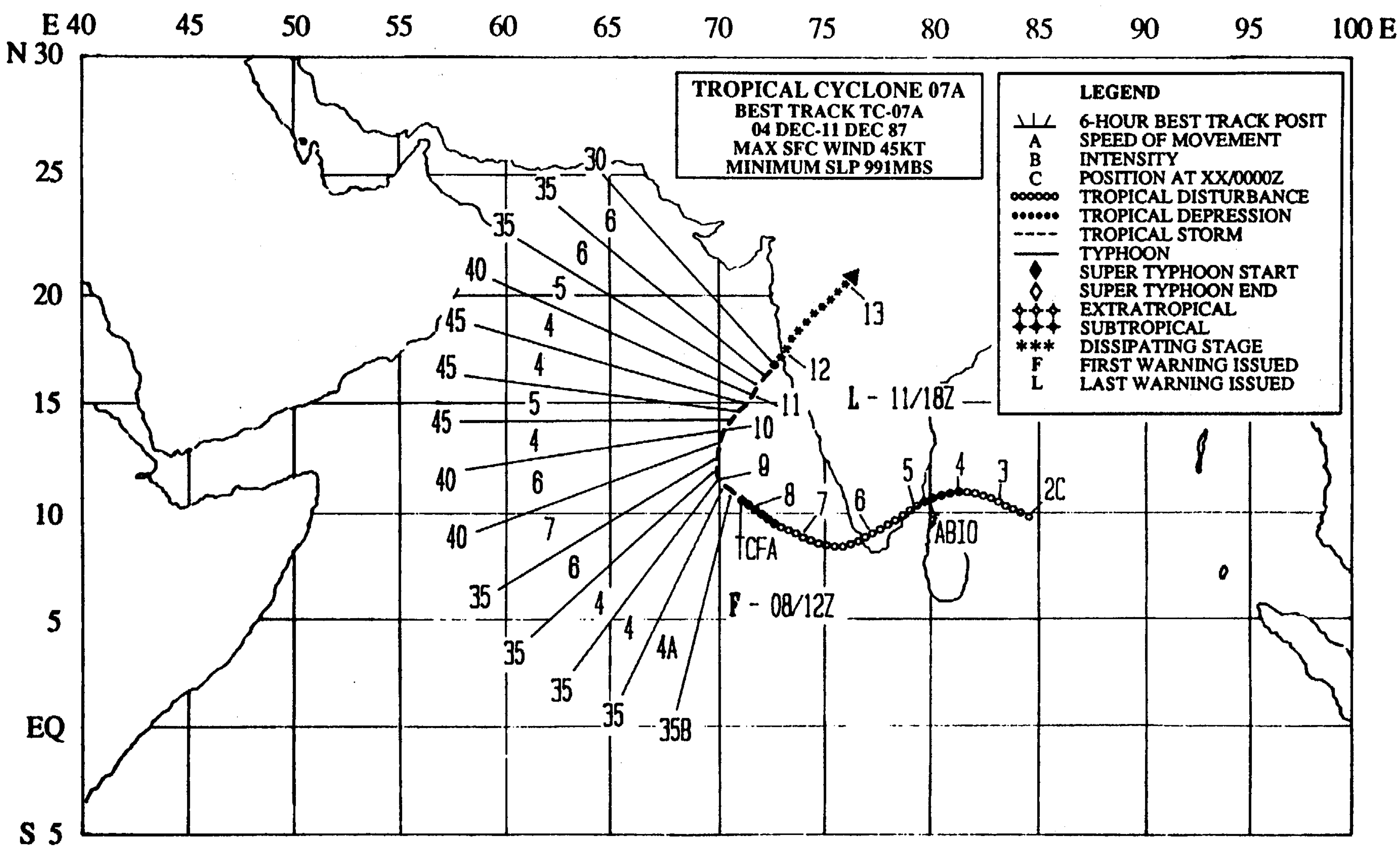


Figure 3-06B-1. Tropical Cyclone 06B became evident on satellite imagery on 8 November as a weakly organized area of convection in the northern Andaman Sea. Initially, it was associated with a broad band of monsoonal cloudiness which extended from the southern India eastward to the central Andaman Sea. First mention of the suspect area occurred on the Significant Tropical Weather Advisory (ABIO PGTW) at 101800Z. Sparse synoptic data implied a closed, low-level cyclonic circulation and associated upper-level divergent flow. As the tropical cyclone's organization increased, a Tropical Cyclone Formation Alert was issued at 102027Z (see above imagery), followed by the first warning at 111800Z. Tropical Cyclone 06B reached a peak intensity of 50 kt (26 m/sec) at 121800Z (see above imagery) as it turned northwestward. Four hours later it made landfall and rapidly weakened while moving into the Eastern Ghats mountains along the coast. The final warning was issued at 130000Z (120929Z November NOAA visual imagery).


TROPICAL CYCLONE 07A
BEST TRACK TC-07A
04 DEC-11 DEC 87
MAX SFC WIND 45KT
MINIMUM SLP 991MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5
L - 11/18Z
F - 08/12Z
TCFA
ABIO
2C
13
12
11
10
9
8
7
6
5
4
3
35B
4A

TROPICAL CYCLONE 07A

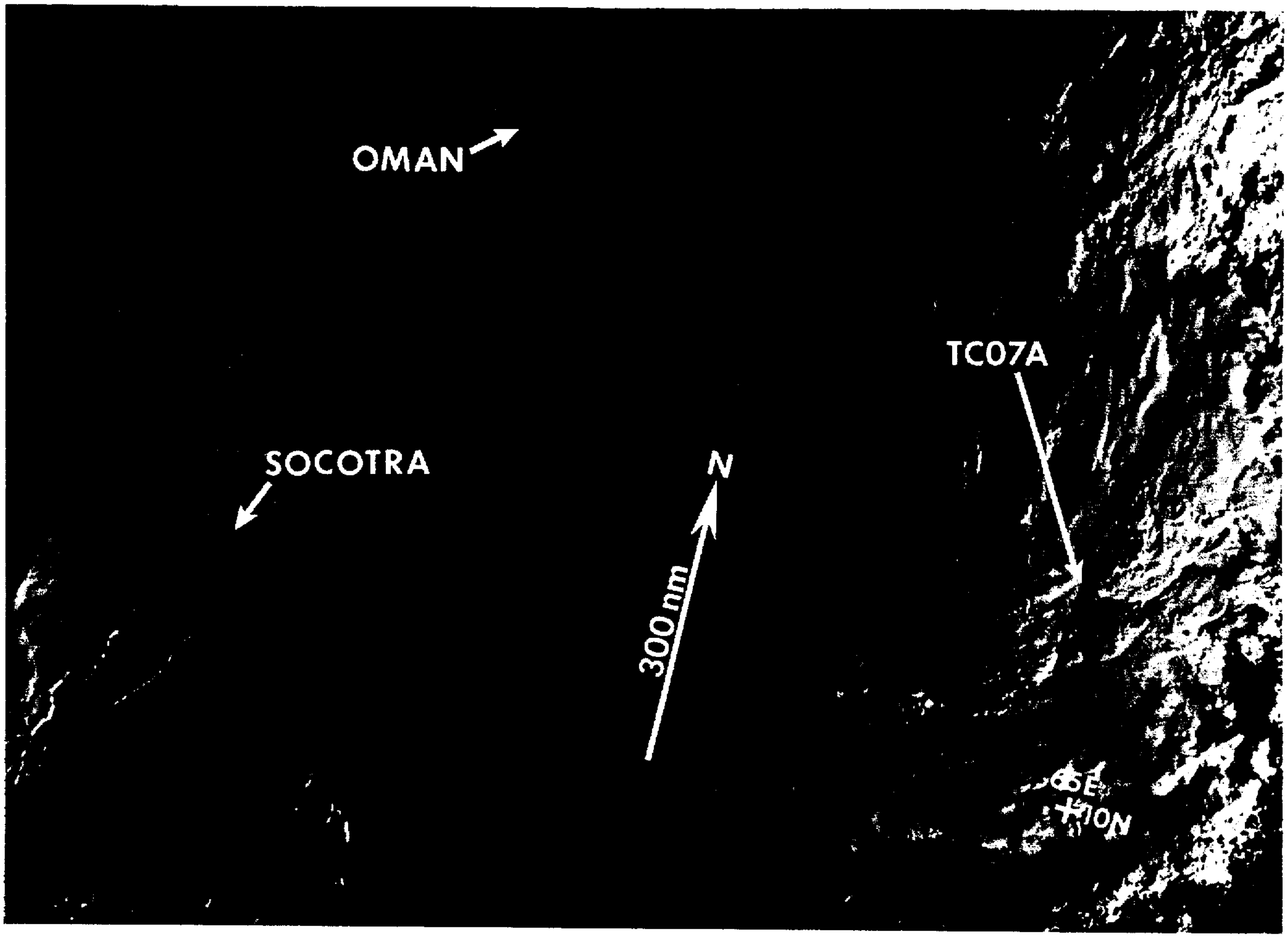
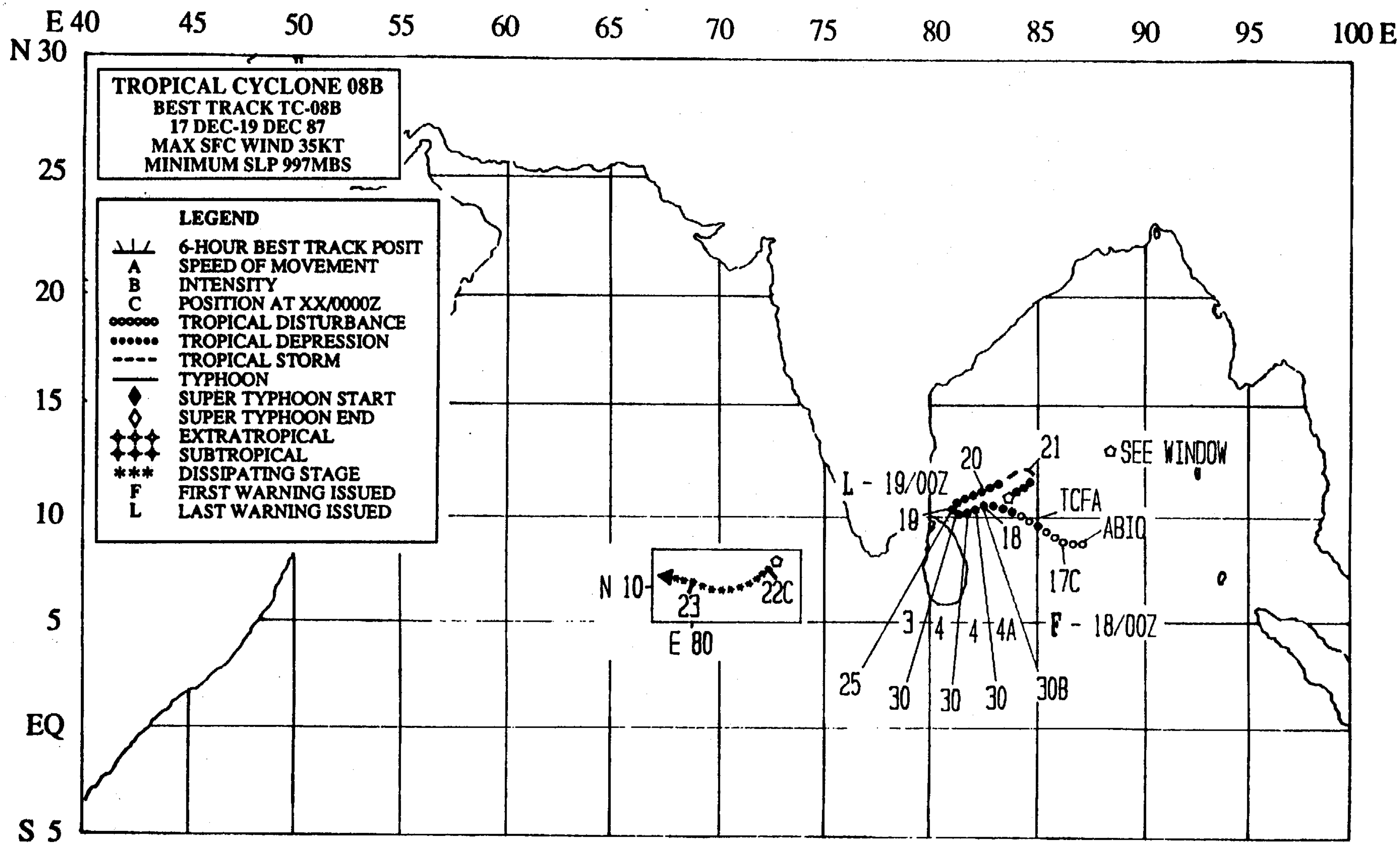


Figure 3-07A-1. Tropical Cyclone 07A was the first significant tropical cyclone in the Arabian Sea during the month of December since 1980. It also marked the first time since 1979 that seven significant tropical cyclones have occurred in the North Indian Ocean. Tropical Cyclone 07A initially developed as an exposed low-level circulation on December 2nd. It slowly intensified, reaching an intensity of 30 kt (15 m/sec) shortly before making landfall on the southeast coast of India at 041900Z, 150 nm (278 km) south of the city of Madras. No warnings were issued on this tropical depression in the Bay of Bengal, however it was mentioned on the 041800Z Significant Tropical Weather Advisory (ABIO PGTW) as having poor potential to develop into a significant tropical cyclone due to its proximity to land. Synoptic data indicated the disturbance maintained its identity as it tracked across the southern tip of India. Once the system moved out over water it reintensified in the Arabian Sea, JTWC issued a Tropical Cyclone Formation Alert at 080930Z. The first warning followed a few hours later at 081200Z, with winds of 35 kt (18 m/sec) based on a satellite intensity analysis (Dvorak, 1984). A maximum intensity of 45 kt (23 m/sec) was reached at 101200Z prior to Tropical Cyclone 07A recurving northward through a break in the subtropical ridge. It then headed toward the western coast of India where increasing vertical wind shear on the 11th weakened Tropical Cyclone 07A before it made landfall at 120000Z, 90 nm (167 km) south of Bombay. No reports of extensive damage or loss of life were received. The above stored data mosaic shows the system just prior to reaching maximum intensity (100202Z December DMSP visual imagery).


TROPICAL CYCLONE 08B
BEST TRACK TC-08B
17 DEC-19 DEC 87
MAX SFC WIND 35KT
MINIMUM SLP 997MBS
LEGEND
6-HOUR BEST TRACK POSIT
A SPEED OF MOVEMENT
B INTENSITY
C POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 40
45
50
55
60
65
70
75
80
85
90
95
100 E
N 30
25
20
15
10
5
EQ
S 5
L - 19/00Z
20
21
SEE WINDOW
TCFA
ABIO
19
18
17C
F - 18/00Z
3
4
4
4A
25
30
30
30
30B
N 10
23
22C
E 80

TROPICAL CYCLONE 08B

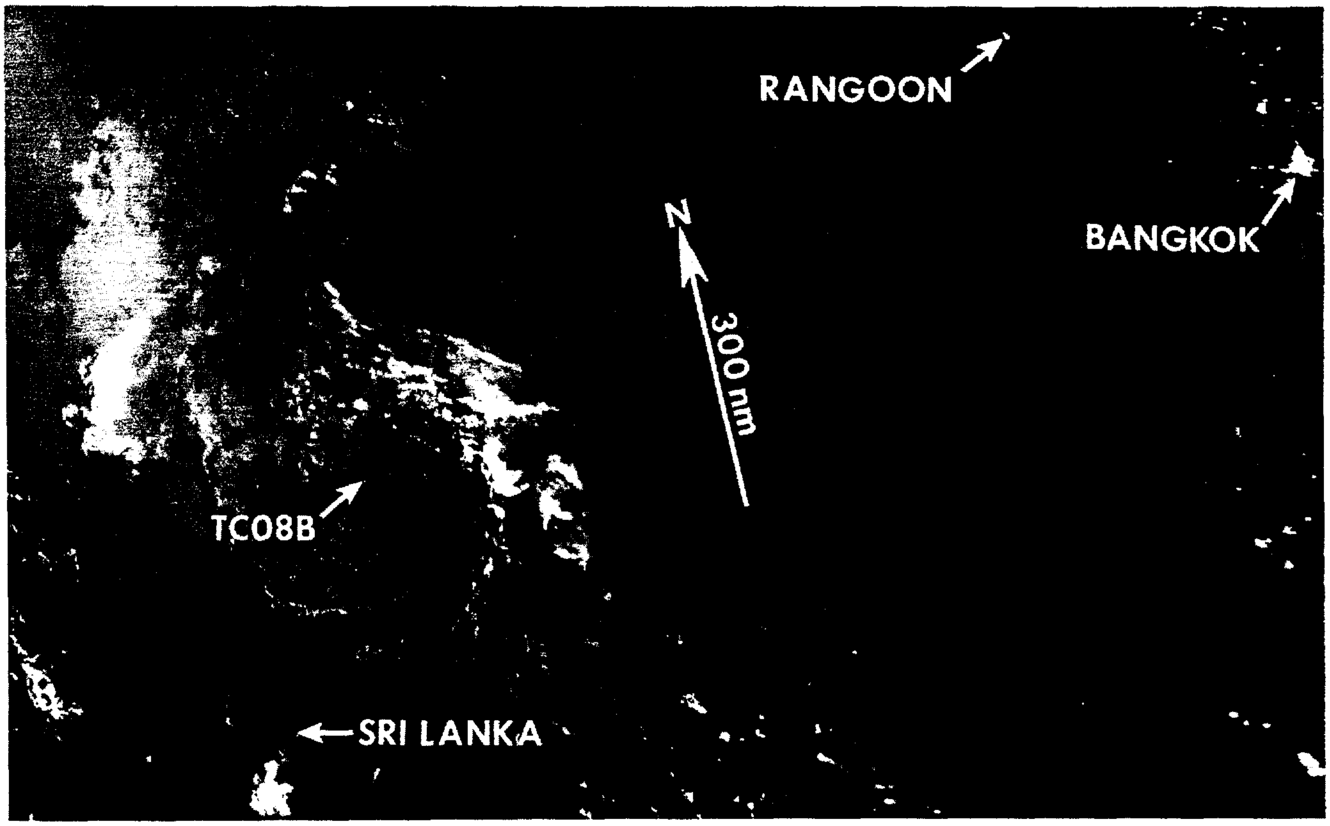


Figure 3-08B-1. Tropical Cyclone 08B was the record-setting eighth significant tropical cyclone to develop in the North Indian Ocean in 1987 and the second system to occur in December. It began as a rapidly organizing tropical disturbance 375 nm (695 km) east of Sri Lanka on the 16th. Tropical Cyclone 08B was mentioned for the first time on the 161800Z Significant Tropical Weather Advisory (ABIO PGTW) and was classified as having fair potential to develop into a significant tropical cyclone based on a low-level cyclonic circulation evident in the synoptic data and an improving upper-level outflow pattern. A Tropical Cyclone Formation Alert (TCFA) was issued the following day at 170800Z when it became apparent the system was increasing in the amount of convection and in organization. Satellite intensity analysis (Dvorak, 1984) estimated 25 kt (13 m/sec) winds at the surface, at that time. The first warning on Tropical Cyclone 08B came six hours later when it developed a central dense overcast and the satellite intensity estimate reached 30 kt (15 m/sec). Tropical Cyclone 08B was initially forecast to move inland near Madras, India and dissipate within 48-hours; however, the system slowed dramatically on the 18th. It changed course at 190000Z and headed toward the northeast. JTWC issued a final warning at 190000Z when it appeared the upper- and lower-level centers had become displaced by strong vertical shear. The exposed low-level circulation center maintained its identity during the subsequent 24-hour period and re-developed its central convection. A second TCFA was issued at 200630Z as the remnants of Tropical Cyclone 08B tracked northeastward and improved in organization. No further warnings were issued, however, despite several satellite intensity estimates of 35 kt (18 m/sec) on the 20th because JTWC believed the intensity was at, or below, warning criteria and not expected to develop further. On the 21st, the tropical cyclone began to weaken and looped unexpectedly back toward the Indian subcontinent (see above imagery). It made landfall on the 23rd on the Indian coast, 165 nm (306 km) south of Madras, India. No reports of major damage or loss of life were received (211229Z December DMSP visual imagery).